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December 1990

## CLiFF Notes: Research In Natural Language Processing at the University of Pennsylvania

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## CLiFF Notes: Research In Natural Language Processing at the University of Pennsylvania

### Abstract

CLiFF is the Computational Linguists' Feedback Forum. We are a group of students and faculty who gather once a week to hear a presentation and discuss work currently in progress. The 'feedback' in the group's name is important: we are interested in sharing ideas, in discussing ongoing research, and in bringing together work done by the students and faculty in Computer Science and other departments.

However, there are only so many presentations which we can have in a year. We felt that it would be beneficial to have a report which would have, in one place, short descriptions of the work in Natural Language Processing at the University of Pennsylvania. This report then, is a collection of abstracts from both faculty and graduate students, in Computer Science, Psychology and Linguistics. We want to stress the close ties between these groups, as one of the things that we pride ourselves on here at Penn is the communication among different departments and the inter-departmental work.

Rather than try to summarize the varied work currently underway at Penn, we suggest reading the abstracts to see how the students and faculty themselves describe their work. The report illustrates the diversity of interests among the researchers here, as well as explaining the areas of common interest. In addition, since it was our intent to put together a document that would be useful both inside and outside of the university, we hope that this report will explain to everyone some of what we are about.

### Comments

University of Pennsylvania Department of Computer and Information Science Technical Report No. MS-CIS-90-95.

Edited by Libby Levison.

**CLiFF Notes**  
**Research In Natural Language Processing**  
**at the University of Pennsylvania**

**MS-CIS-90-95**  
**LINC LAB 190**

**Editor:**  
**Elizabeth Levison**

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**University of Pennsylvania**  
**Philadelphia, PA 19104-6389**

**December 1990**

# CLiFF Notes

Research in Natural Language Processing  
at the University of Pennsylvania

Biannual Report: Fall 1990  
No. 1

Department of Computer and Information Science  
University of Pennsylvania  
Philadelphia, PA 19104-6389

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# 1 Introduction

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## 1.1 Animation from Instructions: from “*Making Them Move*”

Keywords: Animation, Graphics, Motion Verbs, Simulation

We propose here a comprehensive, integrated approach to linking Natural Language instructions with computer animation. The practical goal of this work is “animation from instructions” as a tool in task design. Deep issues abound, however, regarding the nature of instructions given in Natural Language and the transformation of those instructions into actual simulated motion. The major research effort lies in elaborating and implementing several representational levels and the processes active between the levels to reflect well-designed and well-structured information supporting the Natural Language animation connection. This research will allow the experimental evaluation of contemporary ideas in Natural Language semantics, discourse and pragmatics, and potentiate high-level control of animation. The resulting movements depend on the given instructions; planning sensitive to agent task capability; temporal constraint processing; event simulation; motion computed by kinematic; constraint and dynamics processes; and task performance based on detailed agent models. This research requires the close collaboration between Natural Language and computer animation groups. The University of Pennsylvania offers a unique research environment for this effort.

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## 3.1 Masters Thesis on Presupposition as a Discourse Filter

Keywords: Discourse Processing, Constraint Satisfaction Networks, Anaphora

My masters thesis is an exploration of the idea that presuppositions do more than test preceding discourse for presupposed items, i.e. “John’s children are bald” requires that the discourse support the existence of John’s children. I claim that presuppositions can also act as filters on a discourse model in much the same fashion that a modifier restricts possible referents of a definite NP. Consider the following scene: My Set Theory instructor has just handed out evaluation forms and #2 pencils to those who need them. After the forms have been filled out he says, “Please return the pencils”, which refers to the set of pencils lent out. If he said, “Please put down the pencils,” then the set referred to is all pencils being currently used. My claim is that the sets are different because the presuppositions of the surrounding sentence are different, in the first case the pencils are restricted by the presupposition that they were lent, and in the second case that they are being used.

The presuppositions of the above example are essentially preconditions on actions, but there are presuppositions that are founded in more general reasoning. In this case I assume the existence of the relevant information and concern myself with how that information is used to arrive at the appropriate referent. In addition, I am also considering the use of presupposition in resolving more general issues of anaphora. Since I am taking a slightly different approach in determining how a definite NP refers with respect to a discourse, perhaps this will lead to an interesting perspective of discourse segmentation.

## 3.2 Future Directions: Constraint Satisfaction Networks for Discourse Processing

I have adopted and extended Haddock’s semantics for NP reference, which uses Constraint Satisfaction Networks (CSNs) to incrementally refine candidate referents as more of a definite NP is processed. CSN’s and the various algorithms to propagate constraints can be seen as an efficient way to handle the inherent underspecification of fine-grained discourse processing. By fine-grained I mean that as the NP is parsed left to right, the semantics are updated on a word-by-word basis.

I hope that some extension of CSNs can be fruitfully used to represent what is currently available for reference in a discourse. I have extended Haddock’s work to include universal quantification; I intend to incorporate Landman’s theory of plurals and something similar to Kamp and Heim’s Discourse Representation Theory (DRT). In addition I am interested in extending the CSN treatment of incremental processing to the problem of constructing a meaning for a discourse as a whole. I am working under the hypothesis that a discourse contains underspecified information about objects that can be further elaborated upon by subsequent utterances arbitrarily far from the point in the discourse where the objects were introduced. This is similar in kind to the approach of Mellish with regard to definite reference—information leading to the appropriate referent can occur arbitrarily far from the definite NP.

I have extended the algorithm for manipulating the CSN representation to be able to handle ambiguities as to which node in the network a constraint applies to. For instance consider a potential use of “it” in the current discourse, the research summary you are now reading. Several things could be the referent of “it”, depending on the surrounding material. Assume that the following examples are inserted as the second sentence of this paragraph:

- It can take multiple nodes in one argument place—treating the nodes as disjunctive, usually exclusive or. (It= CSN representation).
- It has to be among the set of candidate nodes for co-reference, i.e. if there is an anaphoric link being established, the node has to be salient. (It= node).
- It is controlled by the current needs of the computation, if there is a need to disambiguate the CSN, the algorithm attempts to resolve which node is being constrained, otherwise the disjunction is retained. (It= the algorithm).

This approach assumes that when the “it” is encountered, all salient items that fit the selectional restrictions of “it” are disjunctively linked to the pronoun. As more of the sentence is read, more constraints come to bear on what the antecedent can be, consequently eliminating nodes from the set of possible antecedent nodes.

### 3.3 Recapitulating

My interests center around discourse processing, and I have worked on the role of presupposition acting as a discourse filter with respect to NP (Noun Phrase) reference. This is distinct from theories in which presupposition acts as a test of a discourse which has no role in eliminating possible referents. With this model of anaphora resolution, I am also interested in studying whether a theory of salience in discourse might be affected, but I have done little work on this. The computational model of incremental constraint propagation is promising for discourse processing. I have built on the work of Mellish and Haddock the ability to handle Universal Quantification and extended the disjunction handling ability of CSNs in such a way that anaphora resolution can be incrementally decided. I am close to being able to represent plurals (as per Landman) and providing an implementation of what is immediately available for reference as inspired by DRT.

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## 4.1 Metarules in Tree Adjoining Grammars

Keywords: Syntax, Formal Languages

Metarules allow for a significantly shorter description of grammars, especially of natural languages. They can also capture a number of linguistic generalizations that cannot be expressed in the original grammars. A number of different formalisms use metarules as an extension to the original framework to capture generalizations about the string-generating rules<sup>1</sup>.

In a Tree Adjoining Grammar (TAG) [4], metarules take elementary trees as input and generate new elementary trees as output. A metarule consists of an *input-pattern* and an *output-pattern*. The input- and output-patterns are trees that may contain so-called *metavariables*. If an elementary tree matches the input-pattern, then a new elementary tree is added to the grammar. The new elementary tree is created by filling the metavariables in the output-pattern with the parts of the original grammar-rule that are bound to the same variable in the input-pattern.

Two current Lexicalized Tree Adjoining Grammars (LTAG) for English [1] and French use the concept of *tree-families* to group together all the elementary trees “that share the same subcategorization type”. For example, all variants of clauses that are headed by a verb that subcategorizes for two noun phrases are grouped together in one tree-family. This includes variations like, e.g., Wh-questions, relative clauses, topicalized and passive sentences.

Such variations of the basic declarative sentence occur in almost all other tree-families as well. In the current implementations of the grammars, these trees are explicitly stated for all tree-families. This not only significantly increases the number of trees but, more importantly, misses an important linguistic generalization: the existence of (lexical and syntactic) rules that can be used to describe such variations as passive, topicalization etc. across the tree-families.

By introducing metarules the number of trees that have to be stated in an LTAG can be reduced considerably. Ideally, for every tree-family only one representative tree, the *basic* tree, has to be given; all the other trees can be derived by the application of metarules.

The introduction of metarules into a grammar formalism brings with it a number of problems. The most important is the generative power of the extended formalism. For a wide number of different formalisms such as Transformational Grammar, Van Wijngaarden Grammars, ID/LP Grammars, Categorical Grammars and Head Grammars, the corresponding formalism which includes recursive metarules has a greater generative power than the original formalism. The extended formalisms in fact generate all recursively enumerable languages which makes the string-recognition problem undecidable.

A way around this problem (without giving up the concept of metarules entirely) has been proposed in Generalized Phrase Structure Grammar (GPSG) [3]. In GPSG the application

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<sup>1</sup>‘Rules’ is used with a very general meaning here: It stands for, e.g., the rules of a CFG, the ID-rules of GPSG or the elementary trees of a TAG.

of metarules to the ID rules of the grammar is constrained to the *finite closure* which allows at most one application of each metarule to a given ID rule of the grammar. So in the process of deriving a new ID rule from an old one with metarules, each metarule may be applied only once.

This finite closure restriction has the advantage that an arbitrary number of recursive applications of metarules is ruled out and therefore the generative power of the grammar formalism is unchanged. However, this restriction appears motivated only by the concern for the generative power of the formalism, no other (linguistic) motivation is given.

For TAGs a definition of recursive metarules with limited metavariables has been given which does not increase the generative power of the resulting formalism [2]. But for some cases the descriptive power of this formalism is not strong enough and may not be appropriate for linguistic purposes.

A better approach is to bound the recursive application of metarules based on two (very closely connected) principles of TAGs. In the framework of TAGs a restriction similar to the finite closure restriction can be given which is also motivated by principles of TAG as well as by linguistic reasons:

- 1) One of the features of TAGs is that they *factor the recursion* in the described language in a very compact way, namely by adjunction. So any recursion in the language should be expressed in terms of auxiliary trees.
- 2) TAGs provide an easy way of describing the predicate-argument structure of verbs in one structure (the so-called “co-occurrence restriction”), namely the elementary trees. One of the principles in writing TAGs for natural languages is to keep the elementary trees as close to such predicate-argument structures as is possible.

So the maximum structure that an elementary tree should describe is limited by the principles and basic features of TAGs that guide their construction. This leads to a restriction on the application of metarules that can be formulated as follows:

*The tree resulting from the application of a metarule to an elementary tree is itself a valid elementary tree if and only if it is smaller (in a yet to be defined measure) than a given limit of the grammar.*

This of course implies that the resulting set of new elementary trees will always be finite. But this version of finite closure is derived by principles of the formalism, not merely by stipulation.

The next step will be the implementation of a module that expands a set of elementary trees according to a set of metarules. This module will then be integrated into the XTAG tree editor.

## 4.2 Long Distance Scrambling and Tree Adjoining Grammar

Keywords: Syntax, Formal Languages

This project is being carried out jointly with Aravind Joshi and Owen Rambow. See the abstract on page 62.

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## 5.1 A Formal Characterization of Syntactic and Prosodic Constraints on the ‘Focus’-Particle “Only”

Keywords: Pragmatics, Prosody, Semantics

A previous characterization of the semantic interaction of “only” with what has been called “focus” [Rooth 1985] examined the phenomenon in a limited number of syntactic constructions, and in a limited number of phonetic realizations. The aim of this research is to expand the analysis both phonetically and syntactically. Of concern are constructions where the item to be associated with “only” was extracted, and constructions where the item to be associated with “only” is not the element that received the highest amount of prosodic stress within an utterance. Previous analyses of “only” have proposed rules that moved the necessary items to be adjacent to “only”, in order to facilitate semantic interpretation. The mechanisms in [Rooth 1985] replaced these movement rules, and are thus advantageous in a computational semantic analysis that would work incrementally. Considerations of the meanings of different stress contours in English have been given a preliminary study in [Pierrehumbert and Hirschberg 1987], and these considerations are interesting to study with respect to constructions involving “only”.

In this project, terms will be chosen in order to be able to form discourse characterizations independently of prosodic characterizations. Previous accounts of discourse have often used the term “focus” to mean those item(s) that are both prosodically prominent and that are new in some sense to the discourse. When an association of “only” with an item was recognized, that item was considered to be the “focus” of the utterance in the above sense, as in: (The “focus” in each utterance is the item in capital letters.)

John **only** introduced **BILL** to Sue.  
John **only** introduced Bill to **SUE**.

In this example, the prosodic information differentiates the meaning of the two utterances. The first one can be understood as asserting that if John introduced someone to Sue, that person was Bill and no one else. Similarly, the second utterance could be said to mean that if John introduced someone to Bill, that person could only have been Sue. In addition, in the first utterance, “only” associates with “BILL”, and in the second utterance, “SUE”.

But in data involving extractions, as [Vallduví 1990] has pointed out, the item that “only” associates with does not need to have prosodic stress on it. Below is such an example, in the second utterance in the discourse fragment.

I **know** that someone in that house eats **only** rice. Who is it? Is it Bill?  
No, it's **JOHN** who eats **only** rice.

But in cases like these it could be claimed that the second use of “only” has no semantic import, it is only a repetition of part of a previous utterance. Utterances that do have

instances of “only” associating with a non-focal element do occur in spoken language, however. Below is such an occurrence, from a meeting of the “Finance and Economic Affairs” committee of the Quebec House of Commons. In the context below, it would be very odd to utter Mrs. Maxwell’s first utterance with prosodic stress on “condition”. The reason for this is that the item “condition” was previously mentioned, and it is what Mrs. Maxwell is describing. It is more natural to stress the items that add new information in some way to the discourse than to stress items that the discourse is about.

Mr. Langdon: May I ask you, just to pursue the last part of that question, what the key conditions you see as being crucial on our side are; things we must not give up in order to attain such an agreement.

Mrs. Maxwell: The only condition which is reflected in this document which is strongly felt--

Mr. Langdon: But I am assuming beyond the document.

Although the actual speech waveform for this data is not available at this time, another corpus will be examined that does have actual waveform data available, a corpus constructed by Don Hindle and Tony Kroch.

Questions to cover with respect to this data are the following: What pragmatic formalizations of the use of “only” should be made to correctly capture the data? For example, can these associations of “only” with a non-focal element violate any informational constraints with respect to those outlined in [Steedman 1990]? Since these utterances also can involve different stressed elements, an interesting question is: How can a correct characterization be made of utterances containing “only” and multiple occurrences of stressed items? The formalizations to be made will make use of the insights in [Delin 1990], a syntactic and pragmatic account of cleft-constructions in English.

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### 6.1 Discovering the Feature Set and Word Classes of a Language

Keywords: Language Acquisition

The syntax of a natural language makes reference to features such as [+adjective], [+noun, +proper] and [+indefinite]. Different languages use different feature sets. In order to acquire a grammar for a particular language, one must know what features are used in that language. We have fully implemented an algorithm which uses a variant of distributional analysis ([2, 3, 4, 5]) to discover the feature set of a language. Our method is unique in that it finds features of words rather than word classes.

The algorithm is based upon the hypothesis that features license the distributional behavior of lexical items. Using a very local context, namely the word directly to the left or right of another word, we use a metric to determine whether for each pair of words  $\mathbf{x}$  and  $\mathbf{y}$ , we can conclude with high probability that  $\mathbf{x}$  can occur in every context that  $\mathbf{y}$  can occur in. If this is the case for two words, we say that  $\mathbf{y}$  implies  $\mathbf{x}$ , and we can conclude that  $\mathbf{x}$  has all of the features that  $\mathbf{y}$  has. If it is also the case that  $\mathbf{x}$  implies  $\mathbf{y}$ , then  $\mathbf{x}$  and  $\mathbf{y}$  have the same features. If  $\mathbf{x}$  does not imply  $\mathbf{y}$ , then we know that  $\mathbf{x}$  has at least one feature that  $\mathbf{y}$  does not have, since  $\mathbf{x}$  is licensed to appear in certain contexts which  $\mathbf{y}$  cannot appear in. A set of words with the same features forms a word class. We ran our program on a large corpus of text, and found that meaningful word classes were discovered.

In [1], Chomsky hypothesized that the empiricist's view of language acquisition is untenable because it would be impossible for a child to learn such a complex grammar from such sparse and noisy input unless he was equipped with a great deal of innate knowledge about language. We have shown that no *a priori* knowledge of language, other than our assumption about features licensing distribution, is needed to acquire the feature set of a language. Whether such a feature set is indeed innate remains to be seen; we have shown that arguments for innateness due to the complexity of the acquisition task are not valid.

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### 7.1 The Architecture of a Cooperative Respondent

Keywords: Question answering, Cooperative response generation

Within the natural-language (NL) research community it has long been understood that the conventions of NL communication often oblige question-answering (NLQA) systems to take the initiative when responding rather than answer queries passively. These systems cannot simply translate input queries into transactions on database or expert systems; instead, they must apply many more complex reasoning mechanisms to the task of deciding how to respond. It has been argued that NLQA systems must be able to provide *cooperative* responses [3, 2, 4], which may include such elements as:

- a direct answer;
- information or action that is pertinent to the direct answer;
- information or action pertinent to one or more of the questioner's stated or inferred goals.

Research in *cooperative response generation* (CRG) over more than a decade has yielded a substantial body of literature. However, an analysis of that literature has shown that investigators have almost universally concentrated on modeling *manifestations* of cooperative behavior without directly considering the nature and causes of that behavior itself. If we want to develop NLQA systems that are to be more generally able to respond cooperatively, a different approach is required.

In my dissertation research (to be completed this fall) I take a new approach to the study of CRG. I propose that CRG be viewed as a process of reasoning from principles of cooperation, and argue that those principles must comprise a theory of cooperative question answering that is *respondent-based* (*generative*) rather than *questioner-based* (*descriptive*). Unfortunately, developing a truly adequate generative theory of cooperative communication would be an enormous undertaking, and I do not attempt to do that here.

Instead, I begin by proposing only the simplest set of generative principles necessary to account for the production of a few carefully-chosen examples of naturally-occurring cooperative question-response pairs. Using those principles to ensure analytic consistency, I then subject the example responses to detailed examination. The purpose of the analysis is to ask, for each assertion in a response: (1) what principled reasoning chain could have led to its production, (2) what mechanisms would have provided the knowledge needed during that reasoning, and (3) what insight does that reasoning chain give us into the architectural properties of systems able to produce the response. Based on this investigation I make these claims:

1. A cooperative respondent must maintain an internal model in which it records intermediate states of its progress toward a cooperative response.
2. A cooperative respondent must record and be able to reason about the decisions it has already made regarding what information is to be communicated.

3. Cooperative respondents track the progress that they have made toward the advancement of the questioner's interests.

A domain-independent computational architecture based on these claims is under development [1].

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### 8.1 Zero Pronouns in English

Keywords: Discourse, Syntax, Null anaphora

Zero pronominals are pronouns with no phonetic content. When a zero pronominal fills an argument position, the argument appears to be “missing” from the sentence. So-called “pro-drop” languages like Spanish and Italian allow pronominal subjects and, in some cases, other arguments to be phonetically null. “Discourse-oriented” languages, like Japanese, allow extensive use of zero pronominals. In all cases, this “missing” material is as important to the interpretation of a sentence as the lexical items that are overtly present.

Languages like English, however, have much stronger constraints on the use of zero pronominals. In fact, English has essentially been classified as a language with no zero pronominals other than the subjects of some untensed clauses, which are treated as a special case. This characterization is, however, an over-statement.

While English certainly does not share most of the characteristics of pro-drop and discourse-oriented languages, it does allow the use of zero pronominals in certain syntactic constructions and in certain discourse contexts. Zero subjects are allowed in imperatives (e.g. “(You) leave the room right now!”) and, under some conditions, in conversational style (e.g. “(I) should’ve gotten out while I had the chance.”) Limited instances of zero objects can also be found in English, even in formal, written registers. Event references, in particular, may be phonologically null in object position (e.g. “I know (that)” and “I heard (that)”.) In addition, certain verbs are lexically specified as taking ‘implicit’ arguments.

I am working on a classification and formal account of zero pronominals found in English. This study has two parts. The first is to re-address the question of how these data differ from what is found in pro-drop and discourse-oriented languages. The second is to explore the discourse properties of these zero pronominals, i.e., when does a speaker choose to use them and how does a hearer interpret them? I am exploring the extent to which these questions of discourse function can be answered within centering theory (cf. [5]), a computational model of local discourse coherence. Extensions of centering to treat zero pronominals have already been proposed for Japanese (cf. [5], [12]) and for Italian (cf. [2]), and I am making some comparisons between the centering properties of zero pronominals in English and their properties in pro-drop and discourse-oriented languages.

### 8.2 A Lexicalized Tree Adjoining Grammar for English

Keywords: Grammars, Natural Language processing

The English LTAG project is an ongoing, interdisciplinary effort to develop a large-sized grammar for English using Lexicalized Tree Adjoining Grammar as the grammar formalism. (cf. [4]) There are several goals underlying this project. As a linguist, I am mainly concerned with: the extent to which TAGs provide the right domain of locality for expressing grammatical information and dependencies, the value of a lexicalized representation of a

natural language, the overall soundness of the grammar built, and what insights we can gain about grammatical theory by building a detailed grammar of this size.

Currently, I am looking at how best to treat reflexives (with Megan Moser), and I'm also checking that all current analyses are fully incorporated into the appropriate tree families. The English LTAG is discussed in detail in [1].

Sentences from the English LTAG, as well as from a similar French grammar, are tested using an LTAG parser developed by [6].

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## 9.1 Creole Grammars and the Acquisition of Syntax

Keywords: Language acquisition, Universal grammar, Parameter setting, Creole languages

I am investigating the relationship between the grammars of Creole Languages and the acquisition of syntax. The contribution of this work will be a model of syntax acquisition, based on the notion that the grammar of a Radical Creole<sup>1</sup> is a reasonable first hypothesis of language structure, to be incrementally debugged upon linguistic evidence from the target language. In its strong form, this hypothesis equates the intersecting core grammar of Radical Creoles to the grammatical subset that all languages share as their starting grammar. Testing this hypothesis will provide empirical (dis)confirmation to principles ordering properties of grammars along some markedness scale. Such principles include: the Subset Principle [2], the Maturation Hypothesis [5], the Modularity Principle [8], the Lexical Hypothesis [4]. This model will also predict steps in language development.

It is generally accepted that Creolization occurs through children's attempts to natively learn a pidgin. A pidgin has no native speakers and is used by people with different first languages, whence its variability. In general, the syntax of a pidgin is 'simplified' relative to the languages whose contact it emerged from. What, in the learning efforts of a generation of children, accounts for the transformation of a pidgin into a creole? Whatever the processes involved, they must bear on the broader issue of the acquisition of *any* natural language, since the cognitive mechanisms used by children when Creolization occurs are presumably the same as those used by children in 'regular' contexts of language acquisition.

In the Creole Linguistics literature, there have been various attempts to relate Creole Languages to universal processes of language acquisition [1]. But I have found only one such attempt specific enough to be subject to proof: Bickerton's Language Bioprogram Hypothesis [3], hereafter LBH.

The LBH rests on the premise that the linguistic environment of 'ordinary' children differs from that of 'Creole-creating' children in the regularity and complexity of their respective linguistic inputs. Bickerton convincingly argues that, in the acquisition stage, 'Creole-creating' children had but a limited access to a stable linguistic model. Given the circumstances which availed in the 17th- and 18th-century 'New World' plantation societies in which many creoles were formed — heavy multilingualism; urgent need to communicate across language barriers; restricted access to the language viewed as prestigious — adults were mainly speaking a pidgin. This pidgin was acquired as a late second language, and was heavily influenced by their diverse native languages. Consequently, the pidgin was syntactically impoverished and variable.

This pidgin constituted the bulk of linguistic evidence from which children had to derive the grammar of their native language. Such children, because of the paucity and variability of the available linguistic model, would rely almost exclusively on their genetically wired 'bioprogram' in acquiring language, reducing the triggering effect of the linguistic environment on the emerging grammar.

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<sup>1</sup>Radical Creoles are those formed under most extreme conditions of linguistic instability and variability, cf. [3]. Saramaccan is such a creole.

If the LBH holds,  $G_0$ , the initial grammar of any child, must substantially overlap with  $G_C$ , the intersection of the core grammars of Radical Creoles. In the Principles-and-Parameters approach, this means that the child must start the acquisition process with most parameters initially set as in  $G_C$  (under some idealization). I am formally testing this hypothesis by looking at parameters with 'clear' initial settings (as per the literature on Child Language), and comparing these settings with their counterparts in Radical Creoles.

Another corollary of the LBH is that it makes theoretically feasible the design of a learner which starts off with  $G_C$  as its initial grammar and acquires the grammar  $G_i$  of any language. In other words, a learner may be built that uses  $G_C$  as a 'bootstrap'. Such a learner would initially have its parameters set as in Saramaccan, say, and acquire the model language through 'successive approximations' of the target values given data justifying parameter resettings. The centerpiece of my dissertation is defining the operations taking the learner through these 'successive approximations'.

The use of a 'bootstrap' in theories of syntax acquisition is not novel. The assumption that innate linguistic structures are necessary for the acquisition mechanism to 'get off the ground' has been held in Theoretical Linguistics [6], Creole Linguistics [3], Child Language studies [10], Theoretical Psycholinguistics [7, 9] and Computational Linguistics [2]. What is new in my proposal is the use of the core grammar  $G_C$  of an idealized Radical Creole as the starting grammar  $G_0$  of an automated learner. Unlike many models of language acquisition in the psycholinguistics literature, a computational model forces us to explicitly and formally specify and test our theory of acquisition, and, in that respect, is superior to them. Moreover, the choice of  $G_C$  as a bootstrap is not arbitrary given the history of the formation of Creole Languages and the role of triggers in current theories of language acquisition.

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## 10.1 Natural Language Instructions and the Representation of Actions

Keywords: Knowledge representation, Actions, Behavior

Efforts have been undertaken at the University of Pennsylvania to develop animated simulations of tasks that will drive the behavior of an animated agent from natural-language instructions [1]. In this framework, the need arises to understand what instructions convey about an agent's intended behavior, which they describe by specifying actions to be performed. If we want to use Natural Language instructions to drive an animated agent's behavior, the representation language should be as rich as natural-language is in describing actions: therefore, I have been examining naturally occurring data to understand what the salient characteristics of action descriptions are. What I have found is the following:

1. As far as *individual action descriptions* are concerned,
  - *underspecificity*: there are no *complete* action descriptions; any description can always be further detailed;
  - *variety of qualifications*: formalisms devised up till now (see for example [2], [3]) only represent agent, patient and time of an action, plus possibly spatial locations. However, naturally occurring descriptions offer a much wider variety of qualifications, such as means and manner, termination conditions, side effects to be avoided, and constraints to be satisfied while executing a certain action.
2. As far as *relations between pairs of actions* are concerned, we have:
  - temporal relations;
  - that an action may be described as a test on the outcome or execution of another, for example:  
*To attach the wires to the new switch, use the paper clip to move the spring type clip aside and slip the wire into place. Tug gently on each wire to make sure it's secure.*  
I will call this the *test* relation;
  - that two actions may be related by the *generation* relation, which may be informally characterized by saying that an action is performed *by* executing another, as in:  
*Remove excess paste by wiping gently or blotting with a damp sponge.*

So far, I have collected and analyzed naturally occurring data (some results are reported in [4]). In the future, I plan to refine my analysis of certain classes of data (such as the *test* relation), and to start developing a formalism that embodies at least some of the characteristics described above.

## 10.2 Centering theory and pronominal reference in Italian

Keywords: Discourse, Centering, Null anaphora

Discourse coherence can be considered as a measure of the inference load the speaker imposes on the hearer. Centering [5] accounts for local coherence, namely, coherence within a single discourse segment, in terms of the different moves that a speaker can make (basically, going on to talk about the same entity or switching to another one), and in terms of how these moves are encoded. Centering tries to determine the entity which an utterance most centrally concerns, and to account for the various, different, referring expressions that a speaker may use; among referring expressions, pronouns are a major concern of centering theory.

English, however, offers fewer choices of pronominal expressions than other languages, in that null anaphora is generally not allowed and clitics do not exist. The study of languages which have richer pronominal systems is worthwhile to assess whether the centering framework is sufficiently general to be easily extended. If this is the case, centering could also provide an interesting alternative to the study of pronominal reference in general, given that these studies are often undertaken within syntactic theories that are difficult to extend to inter-sentential phenomena.

Italian allows null anaphora, but only in subject position: centering rules correctly predict that a null subject in Italian is generally interpreted to refer to the subject of the previous sentence. However, these rules need to be refined, because as a result of my analysis I have discovered that the context up to and including the main verb may provide clues that allow the null subject to refer to elements other than the subject of the previous sentence.

In the work done so far, I have mainly been concerned with finding out which syntactic clues may affect the felicity of the use of a null subject (for example gender agreement on past participles, the position of clitics which, in the presence of modal verbs, can be either cliticized onto the main verb, or climb in front of the modal), and with extending centering rules accordingly. This work has been reported in [6].

Future research includes further investigation of the hypothesis that the context up to and including the main verb affects the inference load placed on the hearer. This hypothesis may bear not only on pronominal reference, but also on human processing of language in general.

Furthermore, I'm planning to study two phenomena that centering does not cover: first, the functional role of an utterance may override the predictions of centering; second, a null subject can be used to refer to a whole discourse segment [7]. This latter phenomenon should ideally be explained in the same terms that the other phenomena involving null subject are.

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## 11.1 Syntactic Locality and Tree Adjoining Grammar

Keywords: Syntax, Parsing, Language Acquisition

Theoretical linguistics has as its goal the creation of a theory of linguistic competence, i.e. a characterization of the knowledge which a speaker is said to possess when he knows a language. In a complete, utopian theory of language, such a theory of competence must be augmented by a theory of performance which explains how this competence is put to use in language processing, as well as by a theory of acquisition which details how a child might come to learn a particular language.

In this work, I propose that the considerations of acquisition and processing, as well as the usual constraints of adequacy imposed upon a syntactic theory, point to a characterization of language competence and performance in which the notion of locality plays a central role. In particular, I am investigating the use of the formalism of Tree Adjoining Grammar (TAG) [4], with its particular conception of locality, as the meta-language for our grammatical theory. The TAG formalism restricts the expression of grammatical constraints to local domains in a mathematically precise and linguistically useful way. By thus restricting the statement of the theory of grammar, we can gain insight into the otherwise seemingly arbitrary nature of grammatical constraints as well as into the processes of learning and processing.

This enterprise consists of three pieces of research: the role of TAG in competence grammar, the role of TAG in parsing, and the role of TAG in acquisition. Within the domain of grammar, I have studied the analysis of unbounded dependencies and Wh-movement. Drawing on the work of [5] and [6], I have investigated the adjunction and substitution analyses of movement, interactions of amount quantifier scope with long movement, Irish complementizer agreement, and long distance scrambling, among other topics. All of this evidence bolsters the claim that the limited local domains of TAG elementary trees are sufficient for the expression of the necessary grammatical principles, even in cases such as the ones I have investigated, which *prima facie* are non-local. In the domain of processing, I have proposed a parsing model which is transparently related to the competence grammar (in the sense of [1]), yet maintains certain computational properties necessary for psychological plausibility such as incrementality and processing efficiency [2] [3]. The use of TAG as a representational formalism over which the principles of Government Binding theory are stated and checked provides the key to maintaining both these computational desiderata and the direct link between grammar and parser. Finally, I am investigating the impact of the TAG conception of locality on a model of syntactic acquisition. The local domains over which constraints are stated guarantees a restriction on the domains to which a child must attend in learning a grammar, thereby simplifying the child's learning problem. This yields as a corollary something quite akin to the Degree-0 learnability proposed by [7]. While the particular conception of locality which I am considering is not the only way to accomplish better grammars, parsers, or learners, the utility of this single device in these three varied domains provides evidence, I believe, for the centrality of this notion to the study of human language.

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### 12.1 Verb Phrase Ellipsis and Derivation

Keywords: Ellipsis, Derivation, Semantics

A sentence with an elliptical verb phrase is presumably interpreted with reference to an antecedent sentence, which supplies the missing material. At what level does this “recovery” of missing material take place? For various reasons, neither the syntactic nor the semantic level appears appropriate to resolve VP ellipsis. This has led several authors ([4], [6], [1]) to suggest that the resolution of an elliptical VP requires an examination of derivations of the antecedent. The system of derivation used by these authors is essentially the lambda calculus. This, I argue, leads to several empirical problems in such an analysis. I have developed a simple system of derivation that is intended to be a more “realistic” model of human sentence processing. By using derivations in this system as the solution space for elliptical VP’s, some of the empirical problems mentioned above are solved. However, as pointed out in [5], there are cases of VP ellipsis in which the required material is not part of any conceivable derivation of the antecedent. This may be evidence that the solution to questions about ellipsis must be framed in very different terms: perhaps ellipsis is not a relation between two sentences, but, rather, a relation between a sentence and its discourse context. I hope to explore this alternative further.

In pursuing the work on ellipsis, I have been developing a system of derivation based on TAG [2] and Incremental Interpretation [3]. This system is based on the claim that adjunction in the TAG formalism corresponds to the nesting of assumptions.

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### 13.1 Using Partial Descriptions of Phrase Structure

Keywords: Syntax, Linguistic representation, Parsing

Both phrase structure trees and partial descriptions have been used extensively in the representation and processing of grammatical information. However, only recently has the partial specification of information been applied equally to every kind of information in phrase structure trees. If we allow the structural relationships in a tree to be described with the same degree of partiality as feature structures allow node labels to be described, the resulting representation can support a surprising amount of the work which has been done on natural language. The formalism I have developed to embody this partial description of phrase structure information is called Structure Unification Grammar (SUG). In SUG grammatical information is specified as a partial description of a phrase structure tree. Partial descriptions are combined by equating nodes between descriptions, and when all the equations are done the description must specify a complete ordered tree of feature structures. Because of the flexibility with which information can be stated in SUG grammars, many of the insights from a diverse collection of investigations into the representation of grammatical information can be perspicuously expressed in SUG. Also, many of the investigations into the processing of grammatical information are supported in SUG, again because of its ability to say what is known where it is known. By incorporating all these insights into a single framework, we gain a better understanding of language as a whole.

Although SUG is a very simple formalism, it is quite powerful. Thus it does not help constrain the possible languages. This is intentional; SUG is a tool for the investigation of natural language, not a linguistic theory. However, the fact that the formalism does not embody any constraints does not put the whole burden of characterizing the possible natural languages on the linguistic theory of grammatical information. Constraints motivated by the processing of grammatical information can still be imposed, but they must be stated explicitly in addition to the basic formalism, rather than being implicit to the formalism. By stating them explicitly, various constraints can be tried without changing the underlying formalism in which the grammar is specified. My current work in SUG is investigating several such computationally motivated constraints, with particular concern for the psychological plausibility of the resulting parsing system.

#### 13.1.1 Structure Unification Grammar

In SUG a sentence is derived by combining partial descriptions from the grammar until the resulting description specifies a phrase structure tree with the sentence as its yield. These phrase structure trees are ordered trees of feature structures. The language a SUG grammar uses to describe these trees includes the parent-child relation and the ordering relation, called immediate dominance and linear precedence, respectively. In addition a grammar can specify dominance relations, which specify that there is a chain of immediate dominance relations between the nodes, but does not say how many. This addition allows the expression of long distance dependencies in a single grammar entry. The nodes of the trees

are described with feature structures, which specify the values of various features of the node, such as its category or its agreement markings. These nodes are divided into nonterminals, which are arbitrary feature structures, and terminals, which are atomic instances of strings. These feature structures are allowed to share values, including having the value of a feature be another node. For example, a node may have a feature *head* whose value is one of the node's children. A SUG grammar entry consists of a conjunction of constraints on these node labels and structure relations, with all variables implicitly existentially quantified.

Given a set of descriptions from a SUG grammar, they can be combined by conjoining them and equating some of their nonterminals. The possible sets of equations are only restricted by the need for there to be some tree which is compatible with the resulting description, and by the need for the description to completely specify one of these compatible trees. A description completely specifies a tree if the assumption that anything which is not entailed by that description is false, makes that same description compatible with only that tree. The result of the derivation is this completely described tree. The tree set generated by a grammar is the set of trees specified in this way by some derivation for the grammar. The language generated by a grammar is the yields of these trees.

Because SUG allows complete flexibility in the specification of constraints in the grammar and in the combining of these specifications, SUG is a very expressive and perspicuous formalism. One characteristic which is important to this perspicuity is that the partiality of SUG's representation allows many ambiguities to be treated as simply underspecification. In this way many ambiguities which would seem to require multiple structures to express can be expressed in a single structure which leaves the issue in question unanswered. This ability is especially important in incremental parsing, where many decisions may have to be delayed until more is known about the sentence. Another important characteristic of SUG is that its domain of locality for expressing grammatical information is very large. It can specify both predicate-argument relationships and long distance dependencies within individual grammar entries, thus eliminating the need for feature passing to coordinate constraints across grammar entries. This allows predicate-argument relationships to be specified explicitly within the feature structure labels of nodes, thus freeing the tree structure to be chosen in accordance with syntactic considerations. It also allows SUG grammars to be lexicalized. SUG's ability to put constraints together in a single grammar entry is complemented by its ability to divide groups of constraints into separate grammar entries. This allows some generalities to be captured in the grammar. For example, the grammar entry for a tensed verb can be divided into one grammar entry for the verb root and one for the tense, thus expressing the significance of tense in the grammar. The combination of these three properties allows many of the analyses used in other formalisms to be translated directly into SUG grammars.

### 13.1.2 Parsing and Computational Constraints

As discussed above, SUG is designed to be a framework for investigating computationally motivated constraints on natural language. Much of the work which has been done in this area is done in constrained grammatical formalisms. In that approach the computational constraints are implicit to the formalism. The problem with making the constraints implicit is that if you wish to modify the constraints you may need to drastically change the formalism, thus requiring the linguistic work in that formalism to be redone. Thus each iteration in the process of proposing and testing constraints can be very lengthy. On the other hand, if we allow the constraints to be stated explicitly on top of the basic formalism, we can change constraints without changing the formalism in which the previous linguistic

work has been done. This modularity allows the process of investigating constraints to be greatly speeded up. This is the approach I am following in my research on computationally motivated constraints.

The constraints I am investigating are motivated by the requirements of a psychologically plausible parser. Examples of such requirements are incrementality, determinism, using only a bounded amount of memory, and processing each word in a bounded amount of time. The satisfaction of the first two of these requirements is facilitated by SUG's ability to underspecify information, which allows decisions to be delayed. SUG's expressive power prevents it from satisfying the last two requirements. However, because SUG is not biased toward any particular parsing strategy, the linguistic constraints implied by the computational requirements in SUG are likely to reflect the requirements, not the idiosyncratic characteristics of SUG. For example, various constraints on center embedding, prepositional phrase attachment, and the existence of heavy NP-shift are predicted by these requirements. It is hoped that further investigation into this area will lead to more such predictions.

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### 14.1 The Function of *Okay* as a Cue Phrase in Discourse

Keywords: Discourse, Cue phrases, Prosody

*Cue phrases* convey information about the structure of a discourse rather than semantic content. While there is general agreement that discourse is segmented and that some type of relation exists between segments, details vary considerably between accounts [4] [1] [2] [8] [7]. Since cue phrases provide explicit marking of segmentation and discourse relations, their analysis can help clarify these notions.

This work investigates:

1. uses of the cue phrase *okay*,
2. disambiguation among the various cue and non-cue uses of *okay* and
3. implications for the analysis of pronominal anaphora.

Unless otherwise noted, the data used in this discussion consist of conversations between reference librarians and library users at Northwestern University Library.

#### 14.1.1 Uses of *okay*.

Grosz and Sidner [4] mention *okay* briefly suggesting the following uses: a) completion of a discourse segment; b) I heard what you said, c) I heard and intend to do what you intend me to intend; d) I am done with what I undertook to do; and e) I approve what you are about to do. While (a) and (c)-(e) fit most of the library dialog data, (b) should be replaced by *prompt* for two reasons. First, the occurrence of this use of *okay* solely as an independant utterance, and the rarity of *okay* in narrative is predicted if *okay* is a prompt since in one case, the speaker expects the other participant to continue, and in the other, there is no one to prompt. Second, these instances of *okay* are similar to prompts described by Whittaker and Stenton [10].

#### 14.1.2 Distinguishing cue and non-cue uses.

A problem with cue phrases, noted by Grosz and Sidner [4] and Hirschberg and Litman [5], is that lexical items that serve as cue phrases generally have both cue and non-cue uses. An account must be given of how the cue and non-cue uses can be distinguished. *Okay* has two cue uses: discourse segment completion and prompt (prompt marks continuation of the current segment.) One conclusion of this study is that there is a strong correlation between surface order position and type of use. However, surface order position is not sufficient to determine type of use.

### 14.1.3 Pronominal anaphora.

Certain instances of pronomial reference that occur with the cue phrase *okay* cannot be accounted for in the Grosz and Sidner system without unnecessarily complicating the description of *okay*

(1)

L: Well, why do they criticize it? Do they give you the names of some of these people?

U: Yeah they—**some senators**

L: **Okay**, why don't you look them up either in LUIS or in the card catalog, in the author title catalog?

In (1) above, if *okay* were marking completion of a discourse segment *some senator* should be inaccessible for pronominal reference under the Grosz and Sidner analysis. Either, 1) *okay* is not marking discourse segment completion and an additional type of use must be proposed; or 2) the accessibility of completed segments for pronominal anaphora is not as predicted by Grosz and Sidner and an account of anaphora that allows access to some completed segments is needed. By adopting the reference process proposed by Webber [9], which allows access to a completed sister segment, the pronominal anaphora observed with *okay*, certain de-accenting phenomena observed by Davis and Hirschberg[3] and discourse deixis can all be accounted for.

### 14.1.4 Prosody and Disambiguation

My most current research on this topic investigates the role of prosody in disambiguating uses of *okay*. One part of this work is to explore the applicability of the proposal in Hirschberg and Litman[5] and Litman and Hirschberg[6] to *okay*.

Another part of the work focuses on the ability of subjects to extract certain information about a discourse from instances of *okay* played in isolation. This ability seems to indicate that a surprising amount of information can be conveyed by the prosodic properties of a single item. It also suggests a more principled method for developing discourse-use categories for items such as *okay*.

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### 15.1 Research Interests:

Keywords: Turkish, Scrambling, Topic/focus, Definiteness

I am currently investigating the syntactic phenomenon of scrambling in Turkish with Ümit Turan. I have been concentrating on the role of case-marking and agreement in restricting or allowing scrambling in Turkish.

I am also interested in the pragmatic functions of scrambling. The choice of a particular word order in Turkish is closely tied with the notions of topic and focus.

Also, I have been investigating the differing degrees of referent identifiability found in Turkish noun phrases (e.g. definite, indefinite NPs) and their interaction with word order, case-marking, stress, and the choice of topic and focus.

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### 16.1 Fixed and Flexible Phrase Structure: Coordination in Tree Adjoining Grammars in the Manner of Combinatory Categorical Grammars

Keywords: Grammar formalisms, Coordination, TAGs

TAGs are like phrase structure grammars in the sense that the elementary structures are trees (although not derived from a phrase structure grammar) and the derived structures are trees. They are unlike phrase structure grammars in the sense that the combining operations are tree operations (substitution and adjoining) and not string operations (concatenation and substitution).

Categorial grammars, especially the Combinatory Categorical Grammars (CCG) [1, 2] under certain conditions (which hold for grammars written in CCGs) are equivalent to TAGs[3, 4]. CCGs are unlike phrase structure grammars and also TAGs, in the sense that a CCG does not assign a unique tree structure to a sentence (even in the unambiguous case); it is quite flexible in the assignment of the structure. Almost any contiguous sequence of words can be put together as a constituent in a CCG. This property is exploited by CCGs to give a very elegant account of a wide range of coordination phenomena.

Lexicalized TAGs (with substitution and adjunction) are similar to CCGs in the sense that for each lexical item the elementary tree(s) which is (are) ‘anchored’ on that item can be regarded as the (structured) category (categories) associated with that item. Then for any sequence of lexical items (contiguous or non-contiguous) we can assign a (structured) category. We will attempt to show how a CCG-like account for coordination can be constructed in the framework of lexicalized TAGs. We are also examining gapping and other related phenomena in this context. To the extent it is successful, it shows that an account of coordination can be constructed along the lines of CCG without having to construct constituents corresponding to sequences of lexical items that will ordinarily not be grouped as constituents. More specifically, constituency is defined in the elementary structures and this constituency is preserved and no additional constituent types have to be created. In a CCG being a function is the same thing as being a constituent and vice versa. In our approach we try to show how these two aspects can be kept apart and still the kind of flexibility in the constituent structure that a CCG allows can be realized. We also examine some of the processing implications of this approach.

### 16.2 Machine Translation

Keywords: TAG, Machine Translation

Lexicalized Tree Adjoining Grammar (LTAG) is an attractive formalism for linguistic description mainly because of its extended domain of locality and its factoring of recursion from the domain of local dependencies. LTAG’s extended domain of locality enables one to localize syntactic dependencies (such as filler-gap), as well as semantic dependencies (such

as predicate-arguments). The aim of this paper is to show that these properties combined with the lexicalized property of LTAG are especially attractive for machine translation.

The transfer between two languages, such as French and English, can be done by putting directly into correspondence large elementary units without going through some interlingual representation and without major changes to the source and target grammars. The underlying formalism for the transfer is “synchronous Tree Adjoining Grammars”. Transfer rules are stated as correspondences between nodes of trees of large domain of locality which are associated with words. We can thus define lexical transfer rules that avoid the defects of a mere word-to-word approach but still benefit from the simplicity and elegance of a lexical approach.

We rely on the French and English LTAG grammars that have been designed over the past two years jointly at University of Pennsylvania and University of Paris 7-Jussieu.

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## 17.1 Incremental Planning for Animation of Natural Language Command Sequences

Keywords: Animation, Planning, Natural Language

This work is one ramification of the overall project whose ultimate goal is to derive task animation using natural language instructions [3, 1]. To specify and animate human tasks involving multi-agents, it is appropriate to use sequences of conditional and temporal commands, because they are the means to specify coordinated actions whose activations are typically dependent on other actions and situations. To actually transform command sequences into sequences of motions we need to translate command sequences into rigorous representations, and we need to do some planning to execute the representations. We propose an action formalism in such a way that when it is used for translation of commands and planning, the result would be intuitively acceptable. We suggest a translation scheme which transforms command sequences into representations called *coordinated plans*. We are designing an incremental planner to suggest an appropriate action at each moment according to the coordination constraints contained in the coordinated plan.

In sum, we have found a suitable representation for sequences of natural language commands, especially conditional and temporal commands, which can be systematically interpreted, and we have suggested an incremental planning and execution strategy that is suitable to interpret and execute that representation. One of the remaining problems is to examine the theoretical limitations of the strategy. In particular, we wish to show whether our incremental planning strategy, using our action logic, is sound and decidable. The next pending problem is to fill in the details of the strategy. Specifically, an algorithm should be designed to detect and avoid the violation of protected goals by incrementally finding violation-preventing preconditions at run-time. The final problem is to implement the whole system on *Yaps*, the process simulation system developed by Esakov [2].

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### 18.1 Phonology and Grammatical Category

Keywords: Language processing, Acquisition, Phonology, Lexical structure

During language acquisition, children must learn the grammatical categories of their language, such as noun and verb, and how to assign words to the appropriate class (e.g., "car" is a noun, "go" is a verb). Adults also must assign words to grammatical classes quickly and accurately. In understanding how these tasks are accomplished, researchers try to determine what sources of information are available and used to make grammatical category assignments. Most research on this question focuses on semantic and syntactic information for grammatical class. My own research examines a relatively neglected source of such information, namely phonology. Perhaps certain phonological features are correlated with different grammatical classes, with the concomitant possibility that children and adults have learned and use these correlations.

My investigations of this question have led me to conclude that phonology has been seriously underestimated as an informational source for grammatical class. In particular, large correlations between phonology and grammatical class exist, they can involve thousands of words in the lexicon of a language, children and adults have implicit knowledge of these correlations, and specific hypotheses about the causes of these correlations can be proposed and evaluated. For example, disyllabic nouns and verbs differ in stress in English, with nouns being more likely to have first syllable stress (e.g., compare the pronunciations of "record" in "I bought a record at the store" versus "I will record the concert"). In a variety of experiments, I have shown that adult English speakers have knowledge of this correlation. For example, disyllabic pseudowords such as "bontoon" are more likely to be pronounced with first syllable stress if they act as nouns in sentences than if they act as verbs. In addition to examining speaker knowledge of this stress difference, we have explored a possible basis for its evolution in English. In particular, we have argued that the noun-verb stress difference is due to two factors: (a) a general preference for rhythmic alternation in language, and (b) the tendency for verbs to be more likely than nouns to appear in rhythmic contexts that bias them toward second syllable stress. Using this general hypothesis, we have discovered large rhythmic contexts differences between nouns and verbs, and have used these contexts to predict where the noun-verb difference should be strongest in the English lexicon. Furthermore, a variety of experiments have indicated that stress patterns on words can be altered in predicted ways by the rhythmic contexts in question. These experiments demonstrate that the causes of certain phonological differences between nouns and verbs can be elucidated experimentally. More generally, various characteristics of language change can be subjected to standard psycholinguistic experimental methods. In the future, we plan to relate these various phenomena to models of lexical representation and access in human memory.

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### 19.1 Pragmatic Functioning of Syntactic Constructions.

Keywords: Syntax, Topic/focus, Pragmatic function

I am interested in the use of syntactic constructions to serve pragmatic function in the manner of [1], for example. Specifically, how different syntactic constructions may serve to interact with such pragmatic notions as topic and focus as they may occur cross linguistically. I have secondary interests in semantics, computational linguistics, and language acquisition.

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### 20.1 A Neural Network for Distinguishing Prepositions of Location

Keywords: Connectionist Model, Spatial Relationships, Prepositions

This paper discusses the development of a connectionist model for Annette Herskovits' work on spatial relationships and prepositions of location. This work, which investigates the relationship between perception and language, focuses on the question of how we, when presented with a scene, decide which preposition to use in order to describe it.

According to Herskovits [1], the terms ground or reference object (G) and figure object (F) can be used to classify the objects in a scene. Each preposition can have associated with it a list of characteristics for G and F, as well as a list of characteristics of the relationship between G and F. Herskovits claims that these characteristics can then be used to determine what preposition is appropriate for a given scene. When actual examples from linguistics are considered, however, the properties of F and G, and of the relationship between these two objects do not always correspond exactly to the list of characteristics used to describe a preposition. Herskovits argues that in this instance, the subset of properties for each preposition is relaxed, and a "best fit" is found to describe the scene.

This project investigates the use of a neural network to determine the "best fit" for a given scene. A network to distinguish between the prepositions "along" and "across" was implemented using Gradsim [4], a connectionist network simulator. The network accepts as input the characteristics of a scene. The output is the preposition to be used. Since each input node of the network receives either a high value (0.9) or a low value (0.1), patterns of 0.1 and 0.9 are used to encode a description of the input. It was assumed that G is a ribbon and that F is a line segment. The characteristics encoded as input consist of the position of the end-points of F with respect to G, the orientation of F, and the length of F. The resulting network contained 11 input nodes, 12 hidden nodes, and 2 output nodes. It was trained on a 90 member training set which included examples of "along" and "across," as well as instances where neither is appropriate.

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## 21.1 Long-distance Scrambling and Anaphor Binding

Keywords: Syntax, Free word order

See the abstract on 67.

## 21.2 Scrambling and Adjunct Argument Hypothesis

Keywords: Scrambling, A-movement, A'-movement, Adjunct, Argument

In Government and Binding (GB) theory, movement processes, which typically belong to either A- or A'-movement, are induced by the interplay of the modules of grammar. A-movement (passive, raising) is induced by the interplay of  $\theta$ -theory and case theory, and A'-movement (wh-movement, topicalization) by the requirement of creating an operator-variable structure at LF.

Scrambling (see the Korean examples in (1) among others), however, does not seem to have such a clear UG (Universal Grammar) motivation. It cannot simply be identified with A- or A'-movement.

- (1) a. Sunhee-ka                      Youlee-eykey [chayk han kwen]-ul      senmwulhayssta.  
      Sunhee-NOM                  Youlee-DAT [book one CL]-ACC      gave-a-present  
      b. Youlee-eykey              Sunhee-ka              [chayk han kwen]-ul      senmwulhayssta.  
      c. [chayk han kwen]-ul Sunhee-ka      Youlee-eykey              senmwulhayssta.  
          'Sunhee gave a book to Youlee as a present.'

Recent work on scrambling — [5] for German, [4] for Hindi, and [3] for Korean — show that scrambling exhibits properties of both A- and A'-movement with regard to some diagnostics such as pronoun/anaphor binding, reconstruction, licensing parasitic gaps and floating quantifiers. Concerning this apparently paradoxical character of scrambling, there have been two major proposals: one is to treat scrambling as a movement to *mixed* position ([5]), and the other as a movement to either A- or A'-position ([4]).

In my dissertation I will propose a third possibility to explain the nature of scrambling, namely, **Adjunct Argument Hypothesis**. I hypothesize that there is no structural distinction between arguments and adjuncts in Korean, and possibly in other scrambling languages (cf. [1]). Argumenthood is determined solely by the subcategorization frame of the verb with no direct reflection in the phrase structure. Immediate evidence for this hypothesis comes from 'multiple nominative/accusative' constructions and other case marked time/place adverbials. The major property of scrambling, i.e. optionality, and the case distribution among adverbials, follows from the assumption that any position within a certain domain of the phrase structure is governed by the verb, and hence exhibits all the properties of A-position in the standard GB sense.

In relation to the above proposal, I will explore the following two questions: (1) whether Korean needs a distinct position beyond the government domain of the verb in the phrase

structure, and (2) what would be the proper treatment of Long Distance Scrambling, which exhibits the same properties as local scrambling with respect to all possible diagnostics. Concerning the first question, topicalization will be examined. As to the second question, other linguistic formalisms such as Tree Adjoining Grammar (TAG, [2]) will be explored.

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### 22.1 Question Fragments?

Keywords: Discourse, Pragmatics, Natural Language Interfaces

Sentence fragments are well studied, but question fragments have not been adequately categorized nor has their licensing been satisfactorily analyzed. Previous work that has attempted to explain question fragments includes that of Cohen [3], who recognizes only NP and PP sentence fragments. Grosz's work [5] on the form of ellipsis allows a syntactic interpretation of fragments, but does not attempt to predict when they might occur in discourse. Carberry [2] comes closer with her pragmatic attack: her work on interpreting intersentential elliptical utterances relies on understanding the discourse goals, as well as on focusing strategies. Yet she fails to explain what Yanofsky's [7] study on NP utterances explains, which provides an entire set of fragments that are not deletion generated. In addition, Yanofsky illustrates that an NP utterance can operate independently; it need not be embedded in a complex discourse model.

In an effort to bring together some of this earlier, disjointed work, I analyzed four different dialogues from the literature, and classified the licensing of question fragments in order to better predict their use and occurrence in discourse. I looked not only at the *type* of question fragment, but also at *who* was using it, and *why* the fragment was being used; whether or not question fragments have a particular role in the plan of the discourse. I hope that this work will help to describe some of the mechanisms speakers use in producing and interpreting question fragments.

### 22.2 Animation of Natural Language Instructions

Keywords: Animation, Graphics, Instructions, Verb Semantics

This project investigates generating a short simulation from a set of instructions. There are two motivating factors behind this work: first is the idea that it is easier to follow an animation depicting a task than to follow the often ambiguous Natural Language instructions. The second factor is that it is easier to specify a simulation at a tasks level. The project was conducted using a set of instructions that describe the removal of a Fuel Control Valve from an aircraft.

**Yaps** [4], a Process Simulator developed at the University of Pennsylvania, allows a user to specify high-level animation directives. **Yaps** is linked to the **Jack** animator via a symbolic database specified in **KB** [4], which enables us to describe animation actions while having limited knowledge of low-level animation. The directives can be combined to form action definitions, as well as linked via temporal or causal relationships, to create a task simulation.

For this demonstration, we converted the set of instructions into **Yaps** directives by hand. We established a set of primitive action definitions, and then broke the task down into these primitives. With a final set of eight definitions it is possible to describe and define

the remove and install tasks in their entirety. Examples of verbs which we decomposed into these primitives are: *engage*, *remove*, *reach to*, and *move*. The end result is a short animation of the Fuel Control valve removal.

This work is part of the AnimNL (Animation and Natural Language) project under way at the University of Pennsylvania. The AnimNL group is also investigating linking a parser with a Verbal Analyzer [6] to generate the verb decomposition. We would then connect these projects by feeding the output of the Analyzer directly into **Yaps** to convert the decompositions into action primitives and generate the subsequent animation [1].

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### 23.1 A Cross-linguistic Study of Discourse Phenomena: Toward a Unified Model for Discourse Processing

Keywords: Discourse processing, Pragmatics, Cross-linguistic study, Centering, Anaphora resolution, Topicalization, Particles, Intonation

I am interested in a broad range of discourse phenomena, i.e., phenomena observed in the actual use of language in naturally-occurring discourse. In what follows I will sketch the range of phenomena on which I have done some preliminary study, together with a synopsis of the issues associated with each phenomenon. Being a native speaker of Chinese, I am convinced that a cross-linguistic approach will shed new light in the study of discourse processing and what is generally referred to as “pragmatics.” The objective of this research is to come up with a unified model for discourse processing. In the last section I will briefly discuss some of these larger concerns regarding research strategy and objective.

#### 23.1.1 Centering and Anaphora Resolution

In trying to apply the Centering theory of [1] and [2] to account for anaphora behavior in Chinese, I am interested in two questions. First, what is the relation between the syntactic characteristics of a language (e.g. the number of available pronominal forms, surface word-order, etc.) and its centering behavior? For instance, in English there are three singular third-person pronouns (*he*, *she*, and *it*) while in Chinese there is only one such pronominal form (*ta* in Mandarin, *koei* in Cantonese), and this seems to lead to differing patterns of pronoun usage in the two languages. Second, what is the nature of centering? Are the so-called “backward-looking centers” and “forward-looking centers” features of the utterance or of the language processor? That is, is centering a linguistic phenomenon or is it a cognitive one (e.g. one that relates to the organization of memory)? If centering is basically a cognitive phenomenon, then why would differences in syntactic characteristics among languages lead to differing centering patterns? On the other hand, if centering is primarily a linguistic phenomenon, then how should we encode these differences among languages, perhaps by adding parameters to the centering framework?

#### 23.1.2 Overt and Zero Pronouns in Chinese

In Chinese it is possible to leave an NP-position blank. These blank NP’s are called “zero pronouns” because they are used just like overt pronouns to refer to entities either anaphorically (referring to entities previously mentioned in the discourse) or deictically (referring to entities in the immediate physical context in which the discourse takes place). There are three interesting areas to explore. First, the behavior of the zero pronoun with respect to centering. There seems to be clear differences between the Chinese zero pronoun and the Japanese zero pronoun as described in [3]. Mapping out those differences in precise terms will prove illuminating. Second, how does a native speaker decide when and where to use a zero pronoun or an overt pronoun? What are the differing discourse functions of one versus

the other? Some authors identify animacy as being one of the determining factors in the choice between overt and zero pronoun, but how exactly does animacy affect the choice of pronominal form? Third, in Cantonese the overt pronoun *koei* can sometimes appear in syntactic contexts where it is not expected, such as where all the subcategorized positions of the verb are already filled by other NP's, e.g. *ngo5 soeng2 maai5-dzo2 bun2 syu1 koei5 a3* 'I want to buy the book koei.' Also: *ngo5 soeng2 sei2-dzo2 koei5 a3* 'I want to die koei.' I propose that in such contexts *koei* is acting as a kind of subjunctive marker in the language. What is curious is that subjunctivity marking is neither common nor expected among Chinese dialects.

### 23.1.3 Definiteness Marking

A careful comparison of the patterns of use of definite NP's between English, Mandarin, and Cantonese reveals two interesting facts. First, there seems to be a syntactic(?) prohibition in English on using definite NP's to refer to subparts or possessions of entities when the "possessor" is animate. For instance, 'I injured **the** finger yesterday' is generally not understood as referring to the injury of the speaker's own finger; one would have to say 'I injured **my** finger yesterday.' In many other languages including Chinese and Spanish, the first sentence is the normal way of expressing the fact, whereas in English one must use the possessive. As far as I know, this prohibition in English has not been studied before. Second, what is superficially marked by the definite determiner *the* in English seems to be conflating several different NP statuses into one syntactic marking. In the first place, English *the* is used to mark generic NP's, as in '**The** new student should then proceed to the ID Center.' Furthermore, *the* marks two other statuses discourse entities might have: (a) as a "discourse-old entity," i.e. one that has been mentioned in previous discourse, e.g. 'A man and a woman walked in. **The** woman was a blonde...' (b) as a subpart or possession of a "discourse-old entity," e.g. 'Finally I found John's house, but **the** door was locked.' Crucially, in Mandarin, these two discourse entity statuses are marked distinctly, showing that although these two statuses may have something in common, they must be kept distinct in the discourse model.

### 23.1.4 Topicalization

As is well known, Li and Thompson [4] classifies Chinese as a "topic-prominent" language, as opposed to "subject-prominent" languages such as English. But what does topic prominence really mean? It is a fact that topicalization can occur in a lot more contexts in Chinese than in English. But is it possible to have a common way of describing the discourse functions of topicalization in each of the two languages, so as to form the basis for a more meaningful comparison of the contexts of use of topicalization in the two languages? I see my work as building upon the foundation of Prince's work on topicalization [6], [7], but I would like to extend her work in three aspects. First, while Prince [6] focuses on determining the discourse *constraints* or *conditions* in which topicalization may be used, I will also want to state the discourse *purpose* and *effect* of the process. In other words, I am not just asking *when* a speaker can topicalize, but also *why* a speaker chooses to do so. Second, while Prince [7] shows that different languages use different syntactic devices/forms for the same discourse function, I will attempt to show the relationship between form and function in the converse direction—that different languages use the *same* syntactic form for *different* discourse functions. Third, as alluded to above, I would like to identify a common set of primitives with which we can precisely describe and meaningfully compare the functions of

various discourse phenomena across languages.

### 23.1.5 Antitopicalization

There is a process of right dislocation which occurs in Cantonese and colloquial Beijngese (and perhaps in other dialects, but curiously not in standard Mandarin). By this process, which I call “antitopicalization,” syntactic material in sentence-first or second position may be moved to or reduplicated at the end of a sentence, in the case of Cantonese, after the sentence-final particle. Several aspects of this phenomenon attract my attention. First, antitopicalization is licensed not just by sentence-final *particles* but also by sentence-final *intonation*, implying that the particles and the intonational patterns are in some sense a unified system (see below). Second, what are the discourse conditions on antitopicalization? Why is it possible to antitopicalize in some situations but not in others? And what is its discourse function? Third, it is possible to antitopicalize material which has been fronted to the topic position. How do topicalization and antitopicalization differ and interact? Fourth, what are the acoustic properties of an antitopicalized sentence? For example, is the antitopic usually said with a compressed pitch range? Are the acoustic cues for sentence finality located at the syntactic end of the sentence (i.e. at the sentence-final particle) or at the physical end of the sentence (i.e. at the antitopic)?

### 23.1.6 Sentence-final Particles and Other Discourse Particles

I have done some preliminary study on the rich system of the three dozen-plus sentence-final particles in Cantonese [5]. The main intent, as in the case of the other discourse phenomena, is to find an adequate set of primitives that will allow us to characterize the discourse functions of each of these particles; some of these primitives might be: *speaker/hearer belief*, *mutual knowledge*, *speaker expectation*, *(un)certainly*, *salience*, *inferability*. These particles, for one thing, cannot be simplistically defined as “declarative marker” or “question marker;” most of them can be used with declaratives, imperatives, and interrogatives. Many of the particles are tonal variations of a basic syllable, e.g. *la1*, *la3*, *la4*, *la5*, *lak3*, and a reasonable hypothesis to explore would be that these particles may be analyzed as an abstract particle (e.g. *LA*) plus a tone, where the tone and the abstract particle each has specific discourse functions, and the function of the actual particle is determined compositionally. [5] argues for just such a hypothesis, where it is shown that tone 1 on particles has the discourse function of taking away or reducing the illocutionary force of the utterance. Besides the sentence-final particles, I am also interested in the set of non-final discourse particles in Cantonese. There are two relevant observations here. First, Chinese seems not to have as rich a set of so-called “cue-phrases” as does English, phrases that help display the structure of a stretch of discourse (e.g. North American Chinese frequently employ English cue-phrases such as *anyway*, *by the way*, *okay* in their bilingual speech). What devices then does Chinese provide to display or define discourse structure? Second, some of the discourse particles in one language seem to have “equivalences” in another language, e.g. the function of English *oh* is apparently taken up by the Cantonese particles *a3*, *ai1ya3*, and *o5* (depending on context). We want to ask, is there a unified way to describe the functions of each of these particles and to account for such cross-linguistic “correspondences?”

### 23.1.7 Intonation, Stress and Other Prosodic Features

My final area of interest is prosody, in particular, prosody in a tonal language like Cantonese. There are three specific subareas of inquiry. First, intonational patterns in Cantonese—their

phonetic realization (i.e. their effect on the lexical tones in the utterance) and, of course, their discourse functions. A preliminary study shows that there are three or four such patterns with distinct meanings that primarily affect *only* the tonal contour of the last syllable of the utterance; hence the term “sentence-final intonation.” Second, stress in tonal languages. Since tonal languages use tunes as part of the identity of lexical items, we may not expect them to use tunes to mark stress and accent as in English. How then is stress and accent marked in a language like Cantonese? Preliminary study seems to point to *duration* (syllable length) as the primary device for displaying stress. Third, the learning of a stress-language such as English by native speakers of a tone-language such as Chinese. Just as English-speaking learners of Chinese tend to simulate Chinese tones as differences in stress (e.g. high tones are simulated by a heavier stress), Chinese-speaking learners of English tend to simulate English stress as distinct lexical “tones.” Thus for instance Cantonese speakers assign English syllables to one of three tones: tones 1, 4, and 6 depending on whether the syllable receives stress in English and the position of the syllable. The tone-simulated syllables act completely like native syllables, and can even participate in tone sandhi.

### 23.1.8 Research Strategy and Objective

I will now address the issue of research strategy. There shall be four important features in my research: (1) This research shall be cross-linguistic. I strongly believe that a cross-linguistic perspective helps us identify more clearly what is universal across all languages, and what is particular to a specific language or group of languages. (2) This research shall be based on naturally-occurring speech. Our intuitions at the discourse or “pragmatics” level is just too unreliable and illusive to form the basis of any serious claims. For this reason I will insist that my research be based on transcribed recordings of natural discourse. (3) This research shall be based on the phonetic analysis of the relevant phenomena. Acoustic properties such as tone, intonation, stress and duration, are to be measured and analyzed by computerized tools rather than relying on the researcher’s perception.

The objective of this research plan, as hinted at over and over again in the preceding sections, is to come up with an adequate way of modeling a wide range of discourse phenomena, including those described above. This discourse model might provide a set of primitives (or basic vocabulary) for describing the function, conditions, and effect of the various discourse phenomena. This unified model shall form the basis for meaningful comparison between discourse processes both within a language and across languages. It will also be the foundation of a computational theory of discourse processing.

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### 24.1 Deducing Linguistic Structure from Large Corpora

Keywords: Parsing, Automatic language acquisition, Annotated databases

#### 24.1.1 Automatic Acquisition of Linguistic Structure

The past five years have seen the beginning of a major shift of research focus in natural language processing. After twenty years of focus on on-line systems that crucially depend upon users to adapt to the limitations of the system, a new generation of systems is emerging that both extract information from and summarize pre-existing text from real-world domains. To achieve high coverage in such systems, a wide variety of research breakthroughs will be necessary. One such advance that is critical to truly wide-coverage systems is a technology that allows the automatic acquisition of linguistic structure through the analysis of both literal and annotated text corpora. Research results already in hand suggest that significant progress in this area, at least in the area of syntax, may occur in the next few years.

My students and I, together with our collaborators, have initiated a research program to see how far the paradigm of trainable systems can take us towards the fully automatic analysis of unconstrained text. We are proceeding under the assumption that this work should attempt to combine two different traditions often viewed as mutually exclusive: the research program of generative grammar, as set forth originally by Noam Chomsky, and the research paradigm of distributional analysis, as developed by the American structural linguists resulting in the mathematical and computational work of Zellig Harris.

Our research into distributional analysis has already yielded results that are both surprising and encouraging. We have investigated how accurately the grammatical structure of a sentence can be determined without an explicitly encoded grammar at all, using only automatically compiled distributional statistics of a corpus of text tagged for part of speech. A new sentence analyzer uses this statistical information to hierarchically subdivide new input text into smaller and smaller (unlabelled) grammatical constituents. On a reserved test set, the parser misplaces about 2 to 3 brackets per sentence for sentences of length less than 15 words, and tends to misplace about 5 to 6 brackets on sentences from 30 to 60 words in length. (See [2] for more information.)

To allow this technique to be applied to completely unannotated text, Eric Brill is concurrently experimenting with techniques to automatically derive a tag set for a corpus of text, again using only distributional facts. See [4] and Brill's research report for more information; results to date are very encouraging.

We are also developing a computational model of verb acquisition that uses what we will call the principle of *structured overcommitment* to eliminate the need for negative evidence. The learner escapes from the need to be told that certain possibilities cannot occur (i.e. are "ungrammatical") by one simple expedient: it assumes that all properties it has observed are either obligatory or forbidden until it sees otherwise, at which point it decides that what it thought was either obligatory or forbidden is merely optional. This model is built upon a classification of verbs based on a simple three-valued set of features representing key aspects of a verb's syntactic structure, its predicate/argument structure, and the mapping between

them. This model was originally implemented and tested by working with a small set of hand-selected examples (see [1]); we hope to extend this work using large natural corpora in the near future.

#### 24.1.2 Stochastic Parsing

In another experiment, we have investigated how distributional facts can be used to choose between the multiple grammatically acceptable analyses of a single sentence. We have developed (see [6]) a natural language parsing algorithm for unrestricted text which uses a novel probability-based scoring function to select the “best” parse of a sentence. It also differs from previous attempts at stochastic parsers in that it uses a richer form of conditional probabilities, based on context, to predict likelihood. Tested on a naturally-occurring corpus of sentences (consisting of requests for directions to various locations within a city), the parser determined the correct parse on 37 of 40 sentences.

#### 24.1.3 The Penn Treebank Project

There is a growing consensus that significant, rapid progress can be made in both text understanding and spoken language understanding by investigating those phenomena that occur most centrally in naturally occurring unconstrained material and by attempting to automatically extract information about language from large corpora of natural language. Such data bases are of value for enterprises as diverse as the automatic construction of statistical models for the grammar of both the written and colloquial spoken language, the development of explicit formal theories of the differing grammars of writing and speech, the investigation of prosodic phenomena in speech, as well as the self-evaluation of the adequacy of parsing models, the various formal syntactic theories embedded in those parsers, and the particular grammars of English encoded within those theories.

As a first step towards a much larger corpus, we have developed an annotation scheme for both part-of-speech information and higher-level syntactic structure, along with style books to assure consistent application of the annotation scheme. We have tagged a corpus of over 4 million words of contemporary English text with part-of-speech information, correcting by hand the output of a stochastic part-of-speech tagger. We are currently beginning to annotate higher level syntactic structure, again hand correcting the output of a parser designed to parse unconstrained free text. We expect an output of about 2 million words a year. See [4] for more information.

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### 25.1 The Semantics of Reflected Discourse

Keywords: Discourse structure, Discourse deixis, Reflection, Semantics

My current research is on the interaction between discourse structure and semantics. I am trying to extend the work of Bonnie Webber [1] in discourse deixis to account for the semantics of self-referential discourse. To this end I am applying the technique of procedural reflection (from the programming language 3-lisp) to the construction of a discourse interpreter. This work can be alternately considered to be development of more natural programming languages or to be a synthesis of several components of computational linguistics research in the limited domain of internal state transition events.

### 25.2 Understanding Instructions for Magic Tricks

Keywords: Events, Instructions, Semantics, Perspective

I am interested in the semantics of instructions, and have been investigating how the structure of described events is extracted from a set of instructions. The particular domain I have been exploring is that of magic tricks, a domain which has the additional complexity that several different perspectives are involved in the presentation of the instruction. The logical framework within which I have been attempting to represent the perception of events is a modal logic of belief, with modal operators for each perspective.

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## 26.1 Incrementing Discourse with Negative Sentences

Keywords: Background, DRS, Focus, Information structure, Negation, Presupposition

As we all know, the king of France does not exist. However, he isn't quite dead yet. Russell [4] maintained that there was a scope ambiguity operating in sentences like (1). Either negation has scope over the entire sentence or it has scope over just the VP. The sentence is true or false depending on which scope you choose. Strawson [6] counters with the claim that neither (1) nor its affirmative counterpart have a truth value at all because the subject fails to refer. Into the fray jumps Horn [2], who concludes that negation has unambiguous logical scope over the entire sentence in (1). That the subject seems to survive negation is due to the tendency of that position to be a topic.

- (1) The king of France isn't bald.

This sets the stage for a simple logical analysis of sentential negation augmented by its interaction with the non-logical information structure. Subjects are not the only terms to survive negation. In English, the right intonation signals that terms in the VP also survive. Vallduví [7] described how his representation of information structure could be interpreted as a logical formula with wide scope negation and simultaneously as instructions on unpacking the information. The way the information is unpacked may suggest the survival of terms within the VP as well as the subject, which he dubbed "outsider" terms. By analogy, the term which is understood to be affected by negation is the "insider" term.

The interaction between negation and information structure is quite complex. There are four possibilities. First, as described by Vallduví, it may behave as a focus adverb, having the focus as its insider, as in (2). Second, negation and its insider may be part of the background, as in (3). Both of these first two cases have been given an insightful analysis by Jackendoff [3], including a description of the appropriate intonation contours. Third, the negation itself may be the focus, (4). Finally, there may be no marked focus in the sentence, leading to some kind of default processing of (5). In this dissertation, I define the different contributions each of these types of negation makes in an incremental discourse semantics such as DRS theory.

- (2) A: Beth must have fed Yofi well; she's purring.  
B: Beth didn't feed [NP:F Raisin Bran] to the cat.
- (3) A: Aagh! All our tuna, our leftovers, our milk. What didn't Beth feed to the cat?  
B: Beth didn't feed [NP:F raisin bran] to the cat.
- (4) A: You can have any cereal but Raisin Bran. Beth fed that to the cat.  
B: Beth [NP:F didn't] feed Raisin Bran to the cat.
- (5) A: BETH is at the health food store?  
B: She won't feed junk food to the cat.

Wilson and Sperber [8] claim an affirmative utterance can be divided into foreground and background entailments situated in a hierarchy of entailments generated from the surface structure of an utterance through variable substitution. The background is constructed by replacing the focus with a variable. The increment between the background and the sentences in the hierarchy that entail it constitute the foreground.

While the paper is suggestive, the framework cannot simply be extended for negative sentences because the entailment relationships in the hierarchy will no longer hold. Rather, the background is situated in a hierarchy of open sentences, denoting open propositions. The analysis divides the syntactic surface structure of the sentence into its information structure rather than constructing a separate semantically based representation of it. I consider this an important feature which I wish to maintain in my analysis of negation. A sentential semantic representation does not add anything new to the sentence structure, it can only be a translation into a logical representation of the same structural information. I am not yet familiar enough with Steedman [5] to speak in his terms, but I suspect that he has defined exactly the syntactic representation I have been looking for.

In my analysis, the syntactic representation, which includes the information structure, determines the way in which the sentence information is added to the context in a DRS representation of the discourse. This is a multistep procedure, somewhat reminiscent of Gazdar [1]. First the background is processed with respect to the current state of the DRS. This process may consist of merely a consistency check, or it may require elements of the background to be already present in the discourse. At this point, a discourse effect of Vallduví's link, the topic, is defined. The background may or may not include the negation. Then the foreground increment is processed. If it was not included in the background, then the negation may be an operator for incrementing with the foreground information, as suggested by Jackendoff [3], or it may itself be part of the foreground information. Whether these two distinct increment operations are necessary is not yet clear. (This is work in progress.)

Wilson and Sperber's proposal accounts for the fact that some information in an affirmative sentence is understood to be the point while other information is entailed by the sentence but understood as simply background, the vehicle for making the point. In Horn and Vallduví's proposals, it is similarly maintained that the effect of existential presupposition and the survival of other outsider terms is due to their being in the background. By defining the process whereby the syntactic structure guides the incrementation of the context, I address the question of whether these outsider terms are entailments from a different perspective. That is, the processing of the background portion and a particular context allows a definition of entailment in context which is more accurate than the position that negative sentences alone entail their outsiders.

With the discourse increment of the four cases of negation illustrated by (2)-(5) defined, I plan to investigate the occurrence of incorporated negation within the same framework. In previous work, I argued that the use of a "no" quantifier rather than "any" within a sentential negation limited what affirmative information could be offered as an amendment or repair. I anticipate that a reanalysis of these cases which includes processing of their information structure as outlined above will account for these facts. Further, I plan to investigate whether the optional negative concord in Black English can be analysed as a focus phenomenon.

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## 27.1 Human Sentence Processing

Keywords: Processing, Cognitive Modeling

Why is it that a perfectly grammatical sentence such as:

1. The poets read in the garden stank.

is so much harder to understand than the almost identical:

2. The poems read in the garden stank.

How do people use their knowledge of grammar, meaning, previous discourse, and the world in general, to construct the meaning of sentences which they hear or read?

The aim of my project is to give a concrete computational model of the process of human sentence comprehension. Specifically, I will focus on the representation of the (pervasive) ambiguity which arises during sentence comprehension, and the nature of the resolution of this ambiguity.

As sentence (1) indicates, people sometimes fail to discover a grammatical reading for a sentence their first time through it. I assume that there is a fast, fallible module in the human mind which is specifically adapted for language. When this module fails (as in sentence (1)) other parts of cognition join in to solve the problem. My investigation concerns only this fast, specialized module.

Different theories have been proposed to account for people's preference for certain choices when a (partial) sentence is ambiguous. These theories fall into two broad categories:

- When the processor detects an ambiguity, it resolves that ambiguity based on preferences stated over structural descriptions of the competing analyses. Some examples of this are minimal attachment, which prefers the analysis with the fewest nodes in the parse tree, and right association, which prefers to attach post-modifiers to the most recent possible modified component. (see [1] for a review)
- When the processor detects an ambiguity, it resolves it based on preferences stated over semantic analyses of the competing analyses. [2] proposes *a priori* plausibility and presuppositional parsimony as semantic preference criteria.

[3] provides convincing experimental evidence that it is the latter view which is correct. [4] elaborates this as the fine-grained parallel, weakly interactive model. Within this model of processing, ambiguous analyses are investigated in parallel by the parser, which frequently consults with semantics/pragmatics which express preferences over the various competing analyses.

The aim of my project is to investigate what architectural choices follow from accepting this view of processing advanced in [4]. I will construct a modular system as depicted in figure 1. The representation of grammar and world-knowledge are not central to my current project: I will create simplified, *ad hoc* modules to facilitate the rest of the project. My efforts will concentrate on the memory structures used by the parser for representing competing analyses. Sentences such as (1) and (2) suggest that the processor decides early on

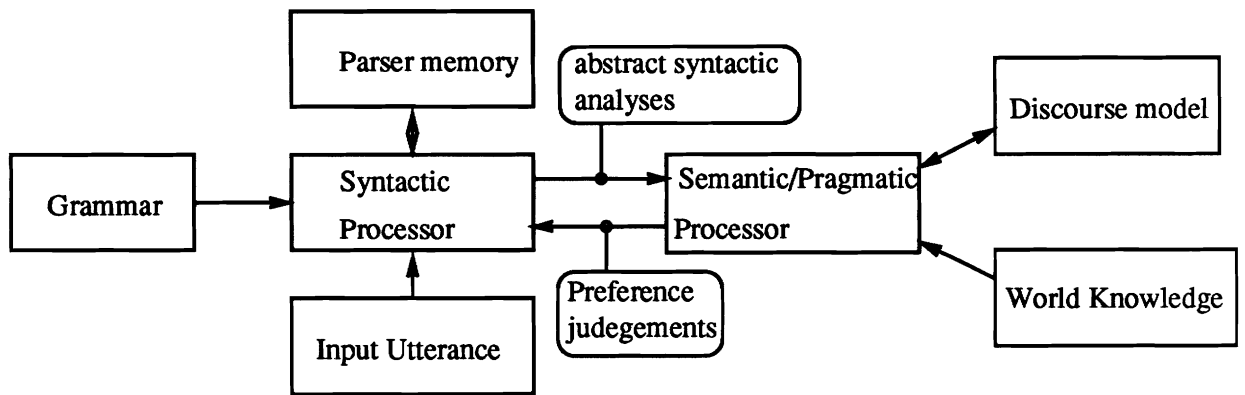


Figure 1: System diagram

as to whether ‘read’ is to be analyzed as the beginning of a relative clause or as the main verb of the sentence. This suggests that the parsing process does not maintain all partial analyses indefinitely, but discards some before reaching the end of the sentence. But the extreme view of early resolution hypothesis (that after reading each word, the processor picks just one competing hypothesis and discards all the rest) probably does not hold either, since there are sentences where the point of ambiguity resolution occurs well after the point at which the ambiguity was introduced, yet people apparently have no problem understanding them. Another direction of this work is how the semantic/pragmatic module should represent the meaning of the utterance so as to be able to inform the syntactic processor about the relative semantic/pragmatic preference of the current syntactic analyses. To this end, I am trying to adapt and extend the reference evaluation model proposed in [5].

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## 28.1 Parsing and Descriptive Succinctness in Natural Language

Keywords: Tree adjoining grammars, Parsing, Succinctness of descriptions

A fundamental problem in Computational Linguistics is the development of grammatical formalisms for natural language (NL) that are not only linguistically competent but also amenable to efficient processing. Recent work in this problem has introduced grammatical models which are more powerful than context-free grammars, such as Tree Adjoining Grammar (TAG), Head Grammar (HG), and Control Grammar (CG). Our research addresses two computational issues concerning these formalisms: (1) parsing complexity, and (2) succinctness of descriptions.

### 28.1.1 Parsing Algorithms

Efficient parsing is crucial to many NL applications such as natural language database access, expert system interfaces, and interactive machine translation, where quick response time is a key measure of system performance. Unfortunately, as greater expressive power is built into the formalism, parsing becomes a more difficult task.

We have investigated the complexity of the parsing problem for TAGs, HGs, and a hierarchy of CGs originally defined by Weir. Specifically, we showed that the formal languages generated by TAGs, HGs and CGs are in the complexity class LOGCFL [4]. This implies that, not only is polynomial-time parsing achievable on serial machines, but parallel parsing can be done efficiently as well (i.e., in polylogarithmic time using polynomially many processors). For the case of CGs, our result is even more significant because the previously best known upper bound on serial parsing was exponential time. We have since developed efficient serial parsing algorithms for the different grammars. In particular, our parsing algorithm for Weir's CG hierarchy is the first polynomial-time algorithm for this class of grammars.

We have also investigated parallel parsing algorithms. The best known serial parsing algorithm for TAGs runs in  $O(|G|^2 n^6)$  time where  $|G|$  is the grammar size and  $n$  is the sentence length. We have designed a parallel TAG parsing algorithm that runs optimally in  $O(|G|^2 n)$  time on an  $n^5$ -processor systolic array [1][2]. Recently, we have extended this to a family of parsing algorithms that runs optimally in  $O(|G|^2 n^6/p)$  time on a  $p$ -processor CRCW PRAM for  $1 \leq p \leq |G|^2 n^5$ . Unlike the systolic algorithm, the PRAM algorithm achieves a speedup with respect to both the grammar size and the sentence length. This is important because for natural language, the grammar size can be very large. This algorithm is currently being implemented on the Connection Machine. We have also developed an NC algorithm for TAG language recognition that runs in  $O(\log n)$  time on a CRCW PRAM, thereby extending previous work on NC algorithms for CFL recognition [3].

### 28.1.2 Descriptive Succinctness

The motivation for modeling NL by grammars more powerful than CFGs is that they seem to afford more succinct descriptions of linguistic phenomena (e.g., subcategorization, *wh*-

movement, etc.) than CFGs. Indeed, the use of a more powerful grammar may reduce the grammar size to the extent that the overall parsing efficiency is actually improved.

Using grammar size as a measure of descriptive complexity, we proved, for the first time, precise mathematical relationships between the size of descriptions afforded by CFGs, TAGs, and Weir's hierarchy of CGs [6]. Specifically, we showed that TAGs are arbitrarily more succinct than CFGs in the following sense: given a TAG generating a context-free language  $L$ , there is no recursive function that bounds the size of the smallest CFG that also generates  $L$ . A more general result holds for Weir's hierarchy of CGs: given a  $k$ -level language and a  $(k + 1)$ -level CG generating this language, there is no recursive bound on the size of the smallest  $k$ -level CG generating the same language. A tool used in the proof is a generalization of Ogden's pumping lemma for CFLs that effectively shows that the Weir's hierarchy is strictly separable, a result that was previously unknown [6].

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## 29.1 Compositional Semantics

Keywords: Semantics, Compositional scope, Intension

My current research interest centers around providing a compositional semantics to a lexical grammar. The assumption is that the semantics should work in tandem with the syntax to discard or approve the (partial) syntactic structure proposed by the syntax. I have been focusing on two issues for this purpose: (1) finding a domain where this assumption yields crucial, hopefully correct, predictions; and (2) finding a candidate semantic framework to base my work on or to dispute in developing an appropriate framework. In addition, there is a hidden issue (3) concerned with checking, in the course of this investigation, that this assumption is indeed well-founded.

As for the first, I have worked on the problem of restricting scoping possibilities, making up a preliminary semantics [3] to the Lexicalized TAG [6] to achieve the effect of simulating the free variable constraint compositionally, as done by Pereira in his 1989 ACL paper [5], but arguing that unlike my proposed system, his implementation is not quite effective in restricting certain types of scoping ambiguities since the system is based on context free grammar for the syntax and on lambda calculus for the semantics. After realizing that I missed some points made by Pereira in his paper, I decided that I should fix the second issue, to a certain degree, before I could address any interesting problem domain.

As a candidate for proper semantics to a natural language, FOL has been considered to be very limited, and there have been a number of attempts to alleviate the limitation in various directions. Montagovian IL (Intensional Logic) [2] is one, and Generalized Quantifier approach [1] is another. My interest at the moment is to check the possibility of TFL (Traditional Formal Logic, originated by Aristotle and developed by F. Sommers [7], to name one), which might be compatible with the generalized quantifier approach, as a natural language semantics. As an experimentation on this idea, I have proposed to consider anaphora as an instance of the inheritance problem, of denotation and connotation, using TFL as a base language [4]. It is questionable, though, if it is appropriate to address the problem of anaphora under the compositionality assumption. On the other hand, since the idea of denotation and connotation in TFL is closely related to the idea of extension and intension, it is considered to be interesting to check on the possibility of attaching a version of IL, or hopefully a grounded version of IL, to a CCG and see how much can be done to explain the natural language phenomena without complicating the semantics. A premature projection is that if it is possible to extend TFL to a degree equivalent to IL, then our semantics will be much more computationally efficient.

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### 30.1 XTAG a portable graphic interface for a Tree Adjoining Grammar System in Common Lisp under X11

Keywords: Graphic Interface, X11, Common Lisp, CLX, Tree Editing, Natural Language Parsing, Tree Adjoining Grammars

XTAG is a portable graphic interface for a Natural Language Parsing System (TAG formalism [3] [4] [8]) which has been developed at UPENN in the Institute for Research in Cognitive Science. It is written in Common Lisp [13] and CLX [12] (the Common Lisp interface to the X11 Window System [11]). The operations supported by XTAG are:

- The editing of trees, and modification of the tree set of a grammar.
- The parsing of sentences with different parsers. The user can examine the resulting parse trees.
- Interactive debugging of a grammar. The user executes step by step combining operations between trees.
- Editing and debugging of the attributes of node and of the equation set which constrains its unification.
- Exploring of the derivation trees associated to every tree resulting from a combining operation (the derivation tree shows which trees were combined and how they were combined to produce the derived tree).
- Tree hard copy.

XTAG is a menu-driven multi-window interface (one window per tree, the number of which is restricted only by the underlying hardware). It is 11,500 lines long and has been written in 9 man-months in a Unix environment (SUN Sparc Station) while the older interface it replaces had required 2 man-years of development on a Symbolics Machine. XTAG uses only Common Lisp and CLX primitives for better efficiency and portability. In particular, it does not require the use of the Common Lisp Object System (CLOS) [5], or any high-level graphic package like GARNET [6] or PICASSO [10]. The reason behind this implementation decision is that none of the toolkits available at the time of the realization of XTAG completely satisfied our requirements because of a lack of versatility, a lack of efficiency or because of distribution restrictions. A more detailed argument can be found in [7]. Our next development efforts will be concerned with adapting XTAG for color displays, adding new features like an undo mechanism (using the item-list data structure proposed by [2]), and extending XTAG for handling meta-rules or Synchronous TAGs [9] used for automatic translation and semantic interpretation. We will also investigate alternative tools for writing a graphics interface in Common Lisp at an intermediary level between the low-level

of CLX and the high-level of elaborate toolkits like GARNET or PICASSO. We will also evaluate the support we can get from tools like ESTEREL [1] (an automata generator able to handle synchronous events) for events management during the programming phase.

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## 31.1 Facial and Vocal Expressions of Emotion for an Animation System

Keywords: Facial animation, Emotion, Intonation, Coarticulation, Conversational signals

Our goal is to build a system of 3D animation of facial expressions of emotion correlated with the intonation of the voice. Up till now, the existing systems did not take into account the link between these two features. Many linguists have shown the relation of intonation of the voice for different emotions to the messages the speaker wants to reveal. Moreover, some psychologists have found some universal facial expressions linked to emotions and attitudes. We will look at the rules that control these relations (*intonation/emotions* and *facial expressions/emotions*) as well as the coordination of these various modes of expressions. Given an utterance, we consider how the messages (what is *new/old* information in the given context) transmitted through the choice of accents and how the placement of these accents are conveyed through the face. The facial model integrates the action of each muscle or group of muscles as well as the propagation of the muscles' movement. It is also adapted to the **FACS** notation (Facial Action Coding System) created by P. Ekman and W. Friesen[1, 2] to describe facial expressions. Our first step will be to enumerate and to differentiate facial movements linked to emotions from the ones linked to conversation. Then we will examine what the rules are that drive the various facial expressions and how their different actions interact.

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### 32.1 Discourse/pragmatics

Keywords: Discourse functions of syntax, Reference, Language contact, Yiddish

I am interested in that part of linguistic competence that underlies the use of particular linguistic forms in particular contexts, where the choice is not entailed by sentence-grammar or truth-conditional meaning. In particular, I am interested in the choice of referential expressions and syntactic constructions. I am also interested in the effects of language contact on this domain. The bulk of my research has focused on English and Yiddish.

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## 33.1 Long Distance Scrambling and Tree Adjoining Grammars

Keywords: Syntax, Formal Languages

This project is being carried out jointly with Aravind Joshi and Tilman Becker. We have been looking at a syntactic phenomenon common in verb-final languages called *scrambling*. In many verb-final languages, such as Japanese, Korean, Hindi and German, it is possible to move arguments of the verb out of their base-generated position. When such movement goes beyond clause boundaries, it is called long-distance scrambling.

Long-distance scrambling poses interesting formal questions because of its double unboundedness: an unbounded number of constituents can scramble over an unbounded distance. It is easy to show that scrambling surpasses the weak generative power of context-free grammars (with an argument similar to [5]), but it appears that the linguistic facts of German do not allow us to show that scrambling surpasses the weak generative power of TAGs [1]. However, by making the additional assumption that all nominal arguments of a verb must appear in the same elementary structure as the verb (“co-occurrence restrictions”), we can exhibit sentences of German which cannot possibly be generated by a TAG. If two elements per clause are scrambled, it is sufficient to have one level of embedding; when only one element per clause is scrambled, three levels of embedding are needed to exhibit co-occurrence violations.

Co-occurrence constraints are linguistically motivated, and must be stated separately for each formal system. It is not *a priori* obvious that co-occurrence constraints in one formal system will map into co-occurrence constraints in another, weakly or strongly equivalent formal system. For example, it is straightforward to show that the sentences which a regular TAG cannot generate can be generated by a “benign” multi-component TAG [6], which is equivalent to a TAG in strong generative power. However, scrambling surpasses the generative powers of “benign” multi-component TAGs as well. We are currently working on the formal argument. We also intend to show that scrambling is beyond the generative power of CCGs (with appropriate co-occurrence constraints).

If scrambling surpasses the generative powers of TAGs (when used as a linguistically motivated representation), then the question arises as to which formalism is adequate. We have shown that the added required power can be obtained from relaxing the definition of a TAG in one of two ways. In the first approach, the immediate dominance relations in a TAG elementary tree are relaxed to allow for other nodes to intervene when the elementary tree is adjoined. This is essentially a version of multi-component TAGs [1, 6]. In the second approach, the linear precedence ordering between sisters is relaxed. This leads to a version of the LD/LP formalism proposed in [2], which we call FO-TAG. The fact that both approaches appear to be adequate from the formal point of view has interesting linguistic ramifications, since the types of linguistic analyses that they imply are quite different. We have been looking at current linguistic analyses of the facts (which are quite inconclusive at present), and will try to evaluate each of the formalisms with respect to their descriptive and explanatory adequacy. Furthermore, the formal properties of the FO-TAG formalism are currently not well understood, and we intend to investigate them further.

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### 34.1 Tree Adjoining Grammar and Stochastic Parsing

Keywords: Tree adjoining grammar, Stochastic parsing

This work is investigating the use of lexicalized grammars, particularly lexicalized tree adjoining grammar, as a means of incorporating structure into the distributional analysis of large text corpora. We hypothesize that the locality of TAG elementary trees provides an appropriately constrained context within which to analyze distributional information beyond the level of trigrams (*cf.* [4, 5]). Initial efforts concentrate on the use of likelihood information derived from a parsed training corpus to guide a suitably extended TAG parser.

### 34.2 An Investigation of Lexical Class Acquisition Using a Recurrent Neural Network

Keywords: Lexical classes, Learning, Neural networks

This project investigates lexical class acquisition using a simple recurrent neural network, following the work of Elman [2, 3]. Like other distributional approaches, for example [1], we hypothesize that the distributional information derivable from large corpora provides enough information to discover useful lexical class information entirely inductively. This approach differs, however, in that it operates not by calculating statistics (such as mutual information) over the  $n$ -grams of tokens present in the corpus, but by seeking to evolve explicit lexical representations over the course of function optimization.

A difficulty with Elman's approach is the question of how to encode input tokens. The obvious approach, encoding them as randomly-chosen bit vectors, leads to the problem of *representational bias* — two distributionally unrelated tokens may be given very similar encodings, unnecessarily making the task of distinguishing them far more difficult. Elman avoids this problem by encoding tokens in "one of  $N$ " fashion (only a single non-zero bit per vector), thus providing initial bit vectors that are equally dissimilar. Although this works well for small examples, it presents a real problem for large corpora: if the number of bits per input token must grow linearly with the vocabulary size, we quickly arrive at networks that are too large to train using the tools currently available.

A novel alternative was explored: encode the input tokens randomly, but rather than judging similarity on the basis of the final internal representations, analyze the *movement* of the internal representations in representation space over the course of learning. A measure called *attraction* was developed to measure the extent to which two tokens' internal representations become more similar as a result of learning, regardless of their initial similarity or dissimilarity. In preliminary experiments, clustering on the basis of the attraction measure appeared impervious to representational bias. It therefore appears to be a tenable method for attempting and evaluating Elman's recurrent-network approach with non-trivial corpora.

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### 35.1 Natural Language Generation as an Intelligent Activity

Keywords: Natural Language Generation, Generator Architecture

The aim of this work is to develop a generator conceived of as part of a general intelligent agent. The generator's task is to provide the overall system with the ability to use communication in language to serve its purposes, rather than to simply encode information in language. This requires that generation be viewed as a kind of goal-directed action that is planned and executed in a dynamically changing environment. In addition, the generator must not be dependent on domain or problem-specific information but rather on a general knowledge base that it shares with the overall system. These requirements have specific consequences for the design of the generator and the representation it uses. In particular, the text planner and the low-level linguistic component must be able to interact and negotiate over decisions that involve both high-level and low-level constraints. Also, the knowledge representation must allow for the varying perspective that an intelligent agent will have on the things it talks about; the generator must be able to appropriately vary how it describes things as the system's perspective on them changes. This project will demonstrate how these ideas work in practice and develop them further.

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## 36.1 Long-distance Scrambling and Anaphor Binding

Keywords: Syntax, Free word order

Locally scrambled antecedents in German bind anaphors, but locally scrambled anaphors appear to reconstruct, suggesting that antecedents and anaphors undergo A- and A-bar movement, respectively. This apparent contradiction can be resolved in several ways. According to Webelhuth [4], scrambling is to a “mixed” position with A-*and* A-bar properties, while Mahajan [3] argues that scrambling can be either A *or* A-bar movement. In this paper, we show that the binding facts are consistent with the view that all scrambling is A-movement (cf. [5]). This work was done with Young-Suk Lee.

Our evidence comes from long-distance scrambling in German. The contrast between the extraposition structure in (1a) and its long-distance scrambling variant in (1b) shows that the anaphor in (1b) occupies an A-position (subscripts and boldface indicate movement and coreference, respectively).

- (1) a. Ich habe vorgehabt, **einander**<sub>i</sub> [die **Gäste**] t<sub>i</sub> vorzustellen.  
I have planned RECIP-DAT the-ACC guests to-introduce  
'I planned to introduce the guests to each other.'
- b. \*Ich habe **einander**<sub>i</sub> vorgehabt, t'<sub>i</sub> [die **Gäste**] t<sub>i</sub> vorzustellen.

Since long-distance scrambling of the antecedent in (2) is consistent with its being A-movement, we conclude that long-distance scrambling is uniformly A-movement.

- (2) Ich habe [die **Gäste**]<sub>i</sub> **einander**<sub>j</sub> vorgehabt, t'<sub>j</sub> t<sub>i</sub> t<sub>j</sub> vorzustellen.

We further conclude from the parallel effects of local and long-distance scrambling on weak crossover in German that all local scrambling is A-movement as well.

Our analysis of scrambling has important implications for the theory of anaphor binding. Since we take local scrambling to be A-movement, we can no longer appeal to reconstruction to derive instances of local scrambling in German where antecedents fail to (strictly) c-command anaphors, as in (1a). Instead, we propose the locality condition in (3) (cf. the notion “command” in [2]; for the definition of “exclusion”, see [1]).

- (3) a binds b iff a and b are coindexed and every c, c=IP, that excludes b also excludes a.

In addition, we argue that anaphor binding in German obeys a thematic constraint—an antecedent’s theta-role in a theta-grid must outrank an anaphor’s. Thus, structurally possible antecedents fail to bind anaphors if their theta-roles belong to different theta-grids (4) or the antecedent’s theta-role is inferior to the anaphor’s (5).

- (4) \*Ich habe [**Hans und Maria**]<sub>i</sub> **einander** versprochen  $t_i$  einzuladen.  
 I have Hans and Maria-ACC RECIP-DAT promised to-invite  
 Intended meaning: 'I promised Hans to invite Maria and Maria to invite Hans.'
- (5) \*Ich habe [**den Gästen**] **einander** vorgestellt.  
 I have the-DAT guests RECIP-ACC introduced  
 Intended meaning: 'I introduced the guests to each other.'

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## 37.1 Knowledge Representation and Reasoning

Keywords: Efficient reasoning, Connectionism

Research in artificial intelligence and cognitive science has made it abundantly clear that tremendous computational activity underlies even the most commonplace intelligent behavior. For example, language understanding, a task that we usually perform so effortlessly, depends upon our ability to disambiguate word senses, recover the phrase structure of input sentences, resolve anaphoric references, impose selectional restrictions, recognize speaker's plans, perform numerous predictions, and generate explanations. Within the knowledge representation and reasoning paradigm, most of the above computations are viewed as *inferences*. This view, however, leads to the following paradox: Most results about the complexity of inference have been surprisingly negative and shown that even very restricted kinds of reasoning turns out to be intractable. Yet the human ability to perform cognitive tasks such as language understanding in *real-time* clearly suggests that there exists a fairly rich class of reasoning that can be performed with extreme efficiency.

Our thesis is that the above paradox can be resolved and interesting points in the tradeoff-continuum between computational effectiveness and inferential power can be found, *provided*, we recognize the symbiotic relationship between the effectiveness of inference, the choice of representation, and the underlying model of computation. We believe that the *structured* connectionist approach which models the information processing properties of the animal brain (at an abstract computational level), offers the appropriate framework for explicating the symbiotic relationship and developing effective knowledge representation systems[1].

We have shown that a class of inheritance and classification problems can be solved extremely efficiently — in time proportional to the *depth* of the conceptual hierarchy. In addition to being efficient, the connectionist semantic network computes solutions to the inheritance and recognition problems in accordance with an evidential formalization. This formalization leads to a principled treatment of *exceptions*, *multiple inheritance*, and *partial matches* — problems that arise due to the ambiguity and incompleteness of common sense knowledge[2, 3]

We have also identified a class of first-order inference that can be computed very rapidly. We show how a knowledge representation and reasoning system can encode a restricted class of first-order sentences and answer a class of queries in time that is *linear* in the *length* of the shortest derivation of the query. The system scales as the response time is *independent* of, and the space complexity is only *linear* in, the size of the knowledge base[4, 5]

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### 38.1 Combinators and Grammars for Natural Language Understanding

Keywords: Computational linguistics, Syntax and Semantics, Speech, Combinatory logic, Cognitive science

My research interests cover a range of issues in the areas of computational linguistics, artificial intelligence, computer science and cognitive science, including syntax and semantics of natural languages and programming languages, parsing and comprehension of natural language discourse by humans and by machine, natural language generation, and intonation in spoken discourse. I also work on formal models of musical comprehension.

Most of my research since completing my graduate work has been on two problems in computational linguistics. The first concerns a theory of natural language syntax and its relation to incremental or cascaded syntactic and semantic processing of spoken and written language. The research demonstrates a direct relation between certain problematic natural language constructions and certain purely local, variable-free, combinatory operations on functions, such as functional composition. The constructions in question involve unbounded dependencies between syntactic elements, such as those found in relative clauses and in coordinate constructions. The combinatory operations are related to some simple combinators which provide a foundation for applicative systems such as the lambda calculus. The involvement of the combinators suggests that the system underlying natural language syntax has affinities with computational systems which minimise the use of bound variables and variable-binding operators, and that it can be understood in similar terms. The research is addressed to a number of questions of practical importance. The weaknesses of most current theories of grammar in the face of the full range of coordination phenomena means that existing computational grammars have the characteristics of unstructured programs – that is, they are non-modular and hard to modify, placing practical limitations on the size and portability of the systems that include them. The standard theories show a similarly bad fit to a number of other phenomena of practical importance, notably phrasal prosody and intonation. Most of my current work is in this latter area, in particular in the problem of synthesising contextually appropriate intonation in limited conversational domains.

My second principal research interest concerns a computationally-based semantics for tense and temporal reference, and exploits the advantages of computational models for capturing phenomena which are presupposition-laden and involve interactions with non-sentence-internal knowledge. The work shows that the primitives involved in this domain are not solely (or even primarily) temporal, but rather are concerned with contingent relations between events, such as causation. This project also addresses a practical concern, for any database that is to be interrogated or updated in natural language making use of tense and related categories is certain to require structuring in the same way. A number of domains are under investigation, including certain problems in the graphical animation of action sequences.

**Selected works:**

- (1987) Combinatory Grammars and Parasitic Gaps. *Natural Language and Linguistic Theory*, 5, 403-439.
- (1988a) Temporal Ontology and Temporal Reference. (with Marc Moens), *Journal of Computational Linguistics*, 14, 15-28.
- (1988b) Interaction with Context During Human Sentence Processing. (with Gerry Altmann), *Cognition*, 30, 191-238
- (1990a) Gapping and Constituent Coordination. *Linguistics and Philosophy*, 13, 207-264.
- (1990b) Structure and Intonation in Spoken Language Understanding. In *Proceedings of the 25th Annual Conference of the Association for Computational Linguistics*, Pittsburgh, PA, June 1990, 9-17.

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### 39.1 Execution of Rapid Action Sequences in Speech and Typing

Keywords: Speech-production, Action sequences, Motor programs

This project is best described by abstracts of the two most recent publications, [1] and [2].

In [1] we provide a summary of several studies of the control of rapid action sequences in speech production, emphasizing findings about the advance planning and hierarchical organization of such sequences. The effects of number of elements in the utterance (its “length”) and other factors on maximum production rates of short utterances lead us to infer that a “motor program” for the whole utterance, prepared in advance, controls the execution of each of its “units”. Findings from studies of typewriting as well as speech production have led us to a model in which the performance of each unit is controlled by two processes arranged in sequence: one (Subprogram Selection) whose duration increases linearly with sequence length, and the other (Command) whose duration depends on type of unit. Quantitative aspects of the production of utterances composed of different types of element suggest that the action unit in speech is the stress group or metrical foot. The virtual identity of the timing of word and nonword utterances implies that the utterance program is sufficiently detailed so it can be executed without reference to learned routines for words stored elsewhere in memory. We review our search for properties of performance that are suggested by the model: First, the time from a reaction signal to the first unit (the latency) increases linearly with utterance length. Second, the maximum length utterance controlled by one program depends on unit size. Third, the effect of utterance length on production timing is localized (intermittent), rather than affecting all parts of the articulatory stream. And fourth, the effect of utterance length on production timing appears in just one epoch per unit.

In [2] we consider what it might mean for execution of an action sequence to be controlled hierarchically. We argue that if production of a sequence consists of the execution of nested constituent subsequences, then it should be characterized by two invariance properties – properties that limit the effects of one part of the sequence on another. (Because one such constituent structure merely partitions the stream of action into “action units,” these properties have wide applicability.) According to Low-Level Invariance, the process that executes a constituent should not be influenced by changes in any higher level constituent. According to High-Level Invariance, changes in a constituent should have at most limited and local effects on higher-level constituents. We report on tests of these two properties in the rapid production of brief utterances and short strings of keystrokes, in which we examine the effects of sequence length, serial position, and unit size on measures of timing. The tests support the existence of hierarchical constituents at the level of the stroke in typing and the stress group in speech, but provide only limited evidence for deeper hierarchical structure.

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### **40.1 Vowel Reduction and Coarticulation in English Dialects**

Keywords: Phonetics, Vowels, Stress, Coarticulation, Reduction, Dialect

Recent developments in speech technology have, for the first time, made possible large-scale studies of the acoustic patterns of natural speech tape-recorded in the field. This dissertation is a study of phonetic variation in dialects of English. Natural conversation taken from sociolinguistic interviews of speakers of 4 very different English dialects is subjected to exhaustive acoustic and phonological analysis. The resulting correlations between instrumental measurements and phonological features are explored, confirming and amplifying classic results found in phonetic “laboratory speech,” but additionally exploring the largely unknown effects of stress and phonological context on vowel quality in unreflecting speech. A great many phonetic alternations are documented for the first time. Differences in phonetic (as opposed to phonological) rules between dialects supports the inclusion of phonetics in linguistics, contrary to traditional views of the role of phonetics in the study of language.

## 41.2 The role of redundancy in the negotiation of collaborative plans

Keywords: Mixed initiative, Summarization, Collaborative plans, Joint action, Negotiation

I am investigating the use of apparently redundant or known information in dialogue, in order to elucidate its role in establishing the beliefs necessary for mutual understanding and joint action. Discourse participants often begin a negotiation with different beliefs[8, 9]. Agreement as to the current state of the world, what goals are to be achieved, what constraints must be met, and how goals can be achieved is often established over the course of the conversation[2].

In a previous study, we noted that conversation between two people is usually of MIXED-INITIATIVE, with CONTROL over the conversation being transferred from one person to another[13]. This contrasts sharply with most previous work on dialogue which assumes that the listener is passive and that one participant has responsibility for directing the course of the conversation. We investigated how this transfer of control takes place and its role with respect to the overall goal of the conversation. We applied a set of rules for the transfer of control to four sets of dialogues. The derived discourse structures indicated that initiative affects the structure of discourse, and that some changes in the initiator role are correlated with redundant utterances, ie. utterances which appeared to add no new information to the dialogue[13].

We also compared initiative in Task Oriented and Advice Giving dialogues and found that both allocation of control and the manner in which control is transferred is radically different for the two dialogue types. We claimed that in the task oriented dialogues, the need to establish and maintain certain mutual beliefs was greatly reduced. The use of redundant information and the apparent differences between dialogue types have implications for a theory of joint action.

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### 42.1 Deictic Reference

Keywords: Discourse, Reference

For the past two years, I have been looking at deictic reference in natural-language discourse. Deictic reference involves the use of expressions such as demonstrative pronouns to refer to things that a speaker believes a listener is currently aware of. Deictic reference may be used in discourse for subsequent reference to events, situations, arguments, etc. whose initial introduction into the discourse required one or more clauses. (In English, demonstrative pronouns are most commonly used for this purpose, although anaphoric pronouns and even zero-pronouns can be so used as well.) My analysis of this phenomenon [7] makes use of the distinction between what can be *pointed to* and what can be *referred to* by virtue of pointing. Using this distinction, I argue that a restricted set of discourse segments yield what demonstrative pronouns can point to in the listener's discourse model, and a restricted set of what Nunberg [5] has called *referring functions* yield what they can refer to by virtue of that pointing.

More recently I have been looking at the difference between definite and deictic noun phrases (NPs), as they occur in natural-language instructions. I noted several years ago [6] that definite NPs (such as *the block*) and deictic NPs (such as *that block*) cannot always be used interchangeably, and that even in contexts that license both forms, they will not always be taken as referring to the same thing. Motivated in part by a recent development in the AI/planning community called *Indexical-Functional Representation* (IFR), I began looking at definite and deictic NPs again. I found that in instructions the differences between the two are striking. For example, I found [8] that one way to license the *accommodation* of a definite NP is to assume that its referent was produced or revealed through an action mentioned earlier (e.g., "Go into the room and bring me back the amulet"). However, no such accommodation will license the use of a deictic NP. A deictic NP requires that the listener be aware of its *demonstratum* through the spatio-temporal context or through previous discourse. (It also requires that the listener be capable of deriving its *referent* from that demonstratum, if the two are not the same.)

### 42.2 Instructions and Plans

Keywords: Instructions, Planning, Animation

Last year, members of the Animation and Natural Language group (AnimNL), led by Professor Norm Badler and myself, began to look at natural-language instructions in order to understand their relationship to behavior. The enterprise is not just of theoretical interest, although I believe it will lead to new insights into natural-language understanding. Rather, it has practical value in terms of its relevance to high-level control of both human-figure animation [3] and what Professor Lou Paul in Penn's GRASP Lab has called *tele-programming*.

What we have discovered over the past year is that there is no one single relationship between instructions and behavior, and thus, most likely, no one single way in which instructions lead to behavior. The tensions lie in whether an agent's behavior is guided more by his/her attempt to ground prior task knowledge in the current situation or by his/her attempt to ground his/her understanding of instructions in the current situation. For example, people who already have some knowledge of a type of task may only make recourse to instructions when they cannot otherwise ground their prior task knowledge to the current situation (cf. [2]). Alternatively, people with little prior knowledge to guide them (for example, people following instructions to reach a particular spot, as in [1]) may focus more on grounding the given instructions. But even in this latter case, agents may still diverge from the given instructions if they recognize that the current situation permits particular optimizations or requires additional actions interpolated between explicitly specified ones (cf. [1].)

In addition to continuing our study of instructions themselves, we will also be attempting to characterize and represent this general knowledge in order to (1) show how it enriches an agent's ability to understand and ground instructions, and (2) how it enables an agent to determine how to carry out some partially specified instruction in the current situation. Endowing a system with these abilities, even in a relatively narrow performance domain, will support much more flexible high-level animation control. (For additional discussion of this project, see statements by Badler, Baldwin, DiEugenio, Jung, Levison, Moore, and White.)

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### 43.1 Incorporating Tense and Aspect into an Event Calculus

Keywords: Tense, Aspect, Event Calculus

The recursive nature of events, implicit in most research on tense and aspect, has not yet been adequately formalized. Towards the end of making this recursive nature explicit, the current research proposes to represent an ontology of events, states and processes using mutually recursive data structures. These representations are to serve as a basis for an event calculus which directly incorporates multiple time scales and thus can serve as an adequate model in which temporal expressions receive their reference. To motivate these recursive structures, consider the sentence “John walked to school this morning.” This sentence evokes an abstract event in which John travels to school and walking is the mode of transportation. Furthermore, it can truthfully refer to an infinity of actual events differing in their decompositions into subevents, as long as these take place in the period referred to by “this morning”. For instance, one such event might consist of the subevents of John walking to his mailbox, checking whether he has received any mail, and continuing on to school. Likewise, the subevent of checking mail might be further decomposed into opening the mailbox, peering inside, and then closing the mailbox. And of course these too may be decomposed. It is not the case, however, that these structures are not well-founded. That is, there are truly atomic events, such as beginning to reach for the mailbox, whose decompositions fall below our perceptual abilities and thus are not normally represented. Of course, one might ask if these representations are really necessary. If one briefly contemplates the sort of information a computer program would need to answer queries such as “When John walked to school this morning, did he check his mail? Did he get anything?”, it is precisely the sort of information alluded to above.

This research should be seen as a natural continuation of past efforts in the area in which progressively more intricate representational machinery is gradually introduced. If progress is to be principled, however, each new piece should be rigorously justified by the existence of natural language data that cannot be accounted for given the current machinery. This methodological point has been made by a number of researchers, including Moens and Steedman in [2], who have proposed the most explicit formalization to date of the recursive nature of events in their contingency-based aspectual coercion network. A rather different set of representational requirements is argued for by Nakhimovsky in [3], [4] and [5], who presents evidence that the notions of qualitative duration and boundary are necessary to represent the meanings of aspectual categories. However, neither of these works ground their representations in a specific model theory. Hence an immediate goal of this research is to integrate and ground these proposals. Towards this end the event calculus proposed by Kowalski and Sergot in [A1], which constitutes a significant improvement over the situation calculus, is being extended to include a recursively defined ontology, multiple time scales and contingent relations. A subsequent goal is to show that this framework serves as a rich setting upon which a simple compositional semantics of temporal expressions can be stated.

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## Appendix

### A CLiFF Talks

#### Spring 1990

Jan 29, 1990      Prof. Bonnie Webber      CIS - UPenn  
Language and Action.

Feb 5, 1990      Kaz Fukushima      University of Arizona  
The Proper Treatment of Every and Some in Japanese.

Feb 12, 1990      Tilman Becker      University of Achen & UPenn  
Metarules for Tree Adjoining Grammars

Feb 19, 1990      Yves Schabes      CIS - UPenn  
Parsing Lexicalized Grammars.

Feb 26, 1990      David Magerman      CIS - UPenn  
Parsing Natural Language Using Generalized Mutual Information.

March 5, 1990      Lyn Walker      CIS - UPenn  
Mixed Initiative in Dialogue: An Investigation into Discourse Segmentation.

March 19, 1990      Sunil Shende      CIS - UPenn  
Parallel complexity of Tree Adjoining Languages (TALs) and Control Languages(CLs).

March 26, 1990      Mike Moore      CIS - UPenn  
Synthesizing a Theory of Action.

April 9, 1990      Mike Moore      CIS - UPenn  
Constraints on Possible Semantic Theories.

April 16, 1990      Jamie Henderson      CIS - UPenn  
Investigating Explicit Computational Constraints on the Human Language Parsing Mechanism.

April 23, 1990      Shirley Steele      Unisys  
Stress and Accent in Continuous Speech Recognition.

April 30, 1990      Dan Hardt      CIS - UPenn  
VP Ellipsis and Discourse.

## Fall 1990

Sept 6, 1990 Prof. James Pustejovsky Brandeis Univ.  
Lexical Decomposition and Perceptual Semantics.

Sept 27, 1990 Kathleen Bishop CIS - UPenn  
Focus on Only: When “only” is not associated with focus.

Oct 4, 1990 Mike White CIS - UPenn  
An Explanatory Theory of Tense and Aspect??

Oct 11, 1990 Christine Nakatani CIS - UPenn  
Beyond Syntax: Using Discourse Context to Resolve Ambiguous PPs.

Oct 18, 1990 Dan Hardt CIS - UPenn  
Vp Ellipsis and Semantic Derivation.

Oct 25, 1990 Barbara DiEugenio CIS - UPenn  
(In Search of) a Language for Representing Action Descriptions.

Oct 25, 1990 Paolo Terenziani Universita di Torino, Italy  
Semantic Interpretation of Tense, Actionality and Aspect.

Nov 8, 1990 Libby Levison CIS - UPenn  
Animation of Natural Language Instructions.

Nov 15, 1990 Michael Niv CIS - UPenn  
An Architecture for Human Sentence Processing, The Semantics Box.

Nov 29, 1990 Jamie Henderson CIS - UPenn  
A CCG-Like System of Types for Trees.

## **B LINC Lab Technical Reports, 1990**

### **The Convergence of Mildly Context-Sensitive**

#### **Grammar Formalisms**

*Aravind K. Joshi*

*K. Vijay-Shanker*

*David Weir*

**MS-CIS-90-01**

**LINC LAB 161**

### **From Simple Associations So Sytematic Reasoning:**

#### **A Connectionist Representation Of Rules, Variables and Dynamic Bindings**

*Lokendra Shastri*

*Venkat Ajjanagadde*

**MS-CIS-90-05**

**LINC LAB 162**

### **Parsing With Lexicalized Tree Adjoining Grammar**

*Yves Schabes*

*Aravind K. Joshi*

**MS-CIS-90-11**

**LINC LAB 164**

### **Animation From Instructions**

*Norman I. Badler*

*Bonnie L. Webber*

*Jugal Kalita*

*Jeffrey Esakov*

**MS-CIS-90-17**

**GRAPHICS LAB 33**

**LINC LAB 165**

### **Structure and Intonation In Spoken Language Understanding**

*Mark Steedman*

**MS-CIS-90-23**

**LINC LAB 169**

### **A Lexicalized Tree Adjoining Grammar for English**

*Anne Abeillé*

*Kathleen Bishop*

*Sharon Cote*

*Yves Schabes*

**MS-CIS-90-24**

**LINC LAB 170**

**Computation and Linguistics Theory:  
A Government Binding Theory Parser Using Tree Adjoining Grammar  
Dissertation**  
*Robert Frank*  
**MS-CIS-90-29**  
**LINC LAB 171**

**Natural Language Generation As An Intelligent Activity  
(Proposal for Dissertation Research)**  
*Robert Rubinoff*  
**MS-CIS-90-32**  
**LINC LAB 173**

**Structure and Intonation**  
*Mark Steedman*  
**MS-CIS-90-45**  
**LINC LAB 174**

**First Steps Towards An Annotated Database of American English**  
*Mitchell P. Marcus*  
*Beatrice Santorini*  
*David Magerman*  
**MS-CIS-90-46**  
**LINC LAB 175**

**Part-Of-Speech Tagging:  
Guidelines For The Penn Treebank Project  
(3rd Revision)**  
*Beatrice Santorini*  
**MS-CIS-90-47**  
**LINC LAB 178**

**Mathematical And Computational Aspects Of Lexicalized Grammars  
Dissertation**  
*Yves Schabes*  
**MS-CIS-90-48**  
**LINC LAB 179**

**Structure and Ostension In The Interpretation of Discourse Deixis**  
*Bonnie Lynn Webber*  
**MS-CIS-90-58**  
**LINC LAB 183**

**Description Succinctness of Some Grammatical Formalisms  
for Natural Language**

*Michael A. Palis*

**University of Pennsylvania**

*Sunil Shende*

**University of Nebraska**

**MS-CIS-90-82**

**LINC LAB 187**